

Odvráčená strana vesmíru

Tmavá hmota a tmavá energia

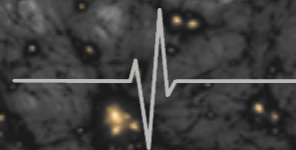


dr. Norbert Werner

Odvrácená strana vesmíru



Tmavá hmota a tmavá energia



dr. Norbert Werner

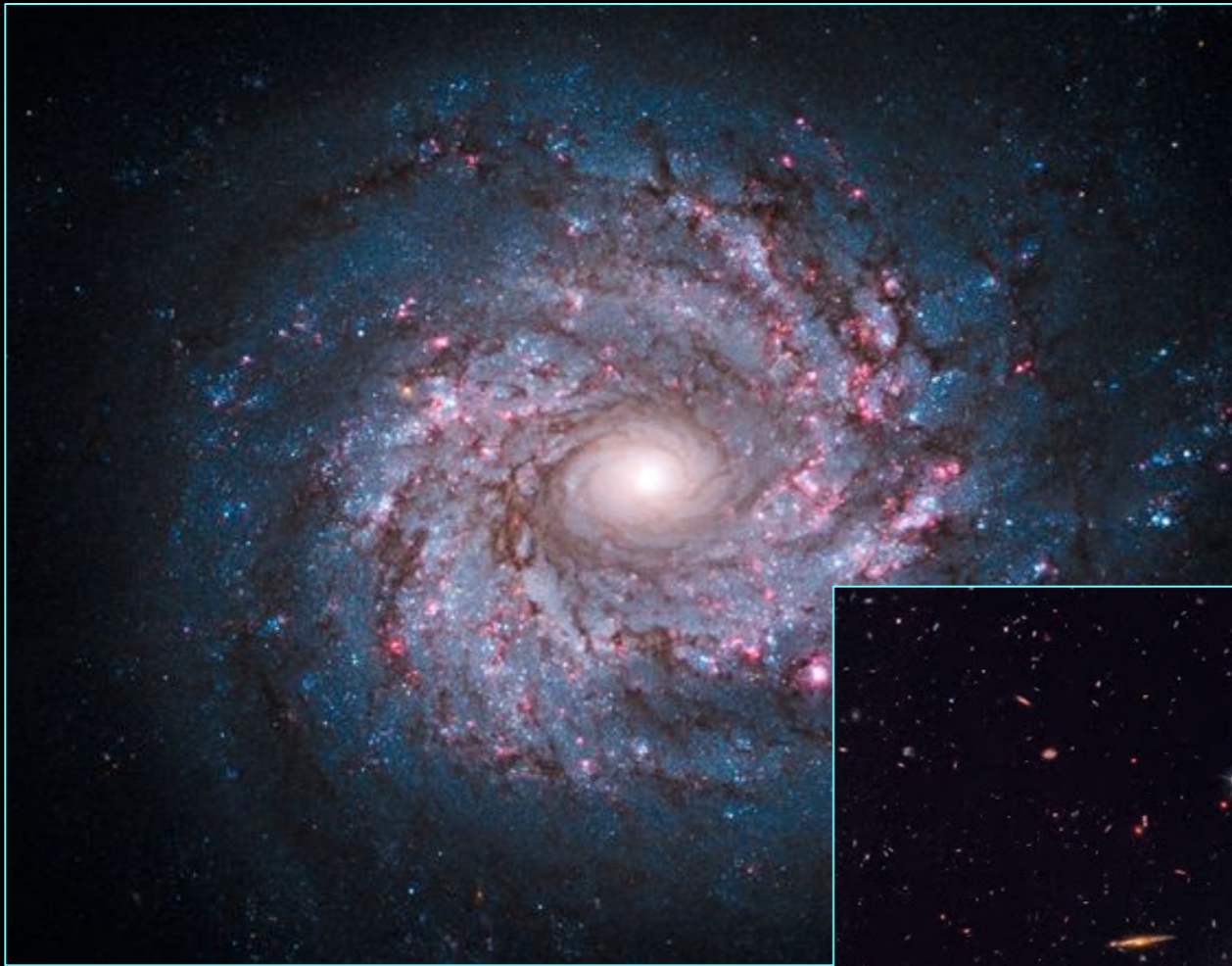


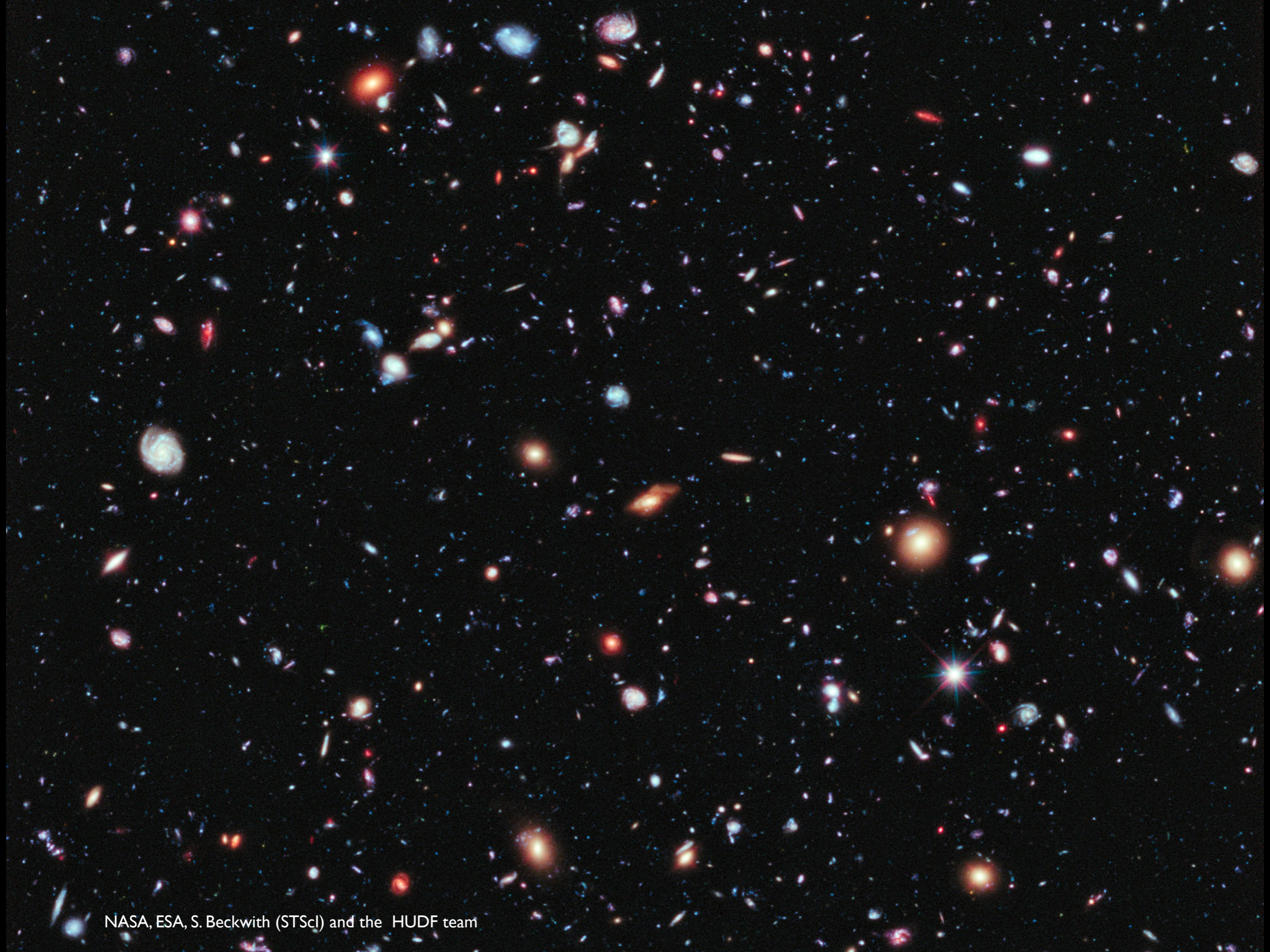


Credit: Nick Risinger

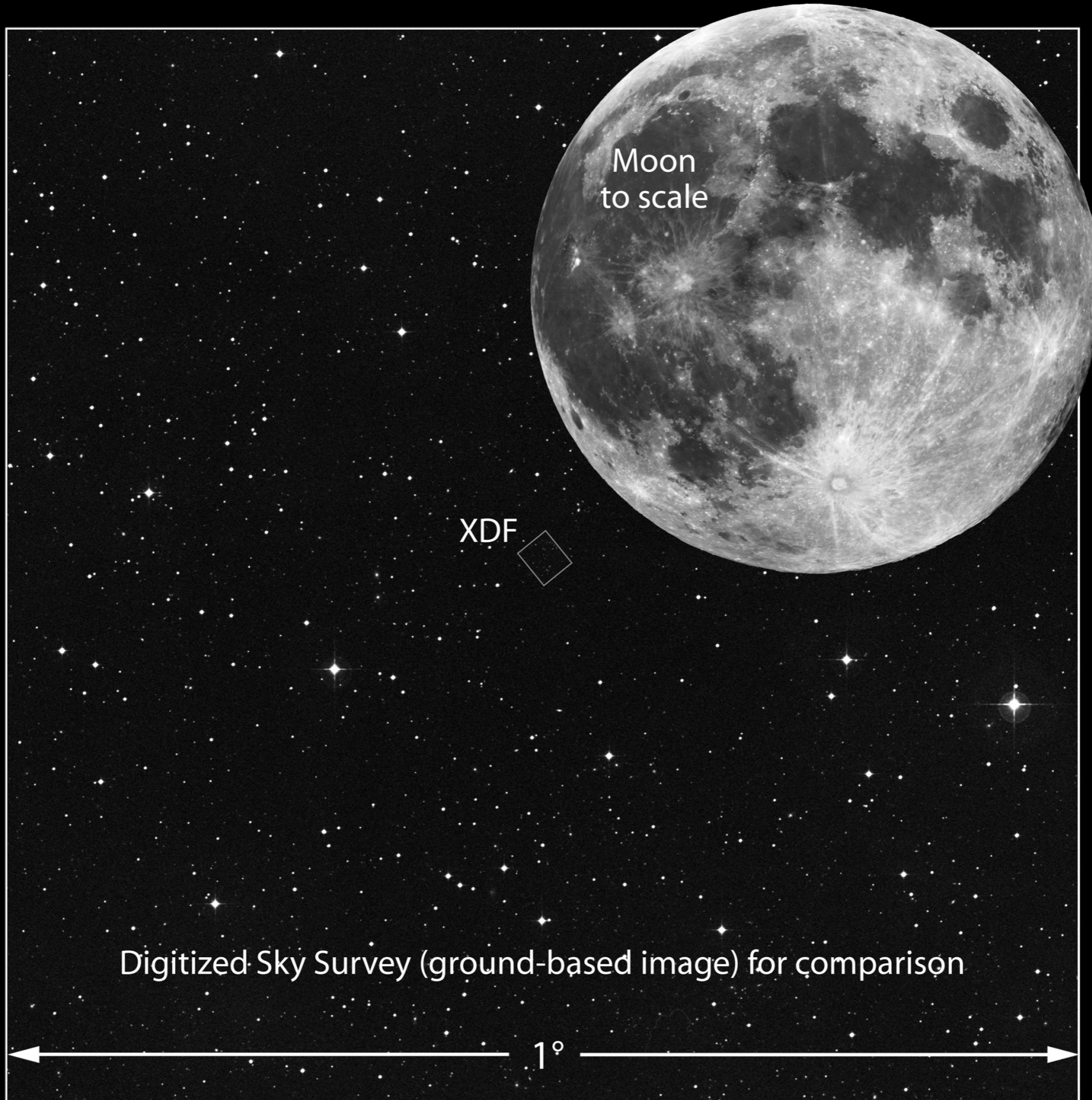


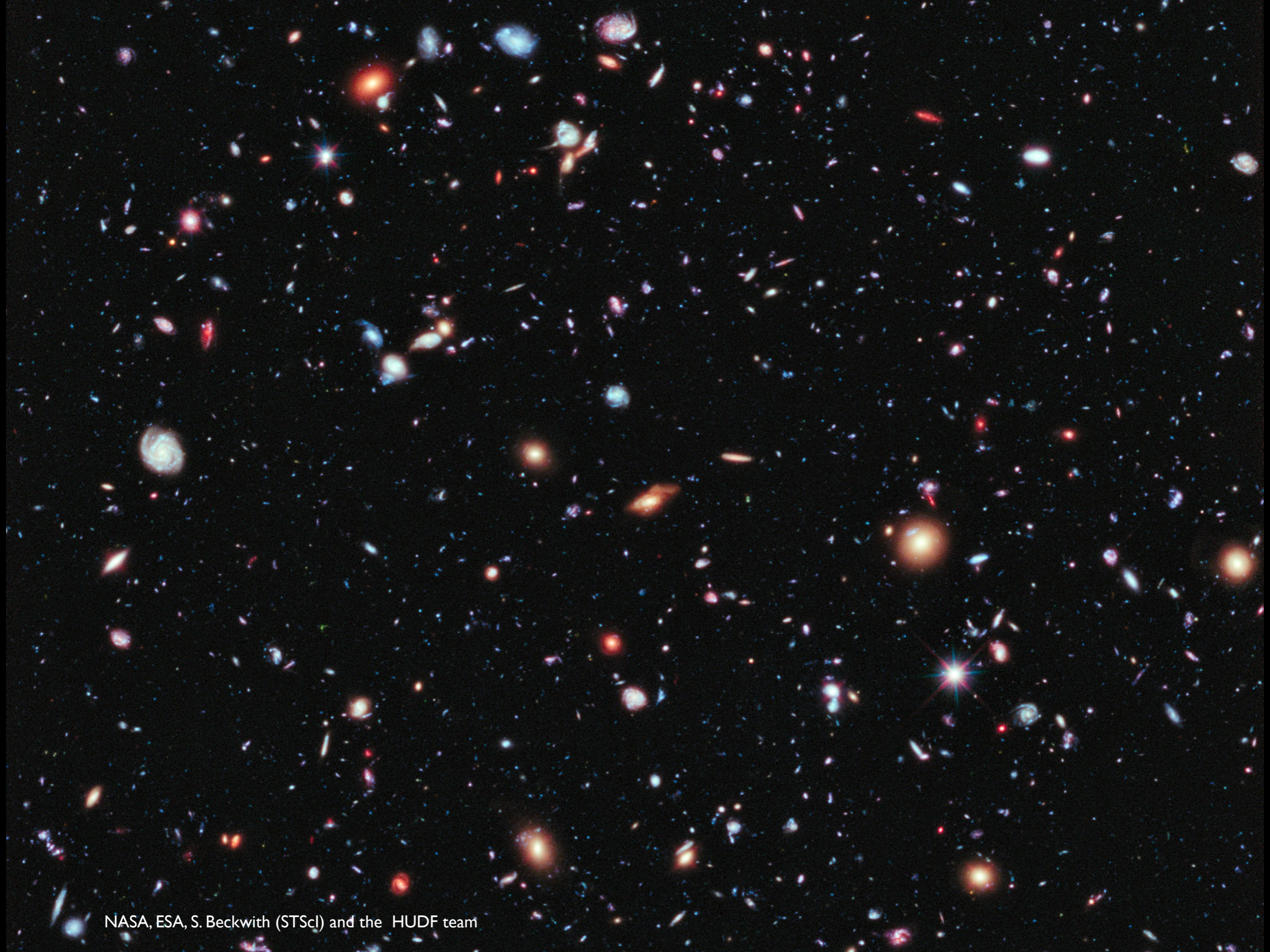
Galaxia v Androméde

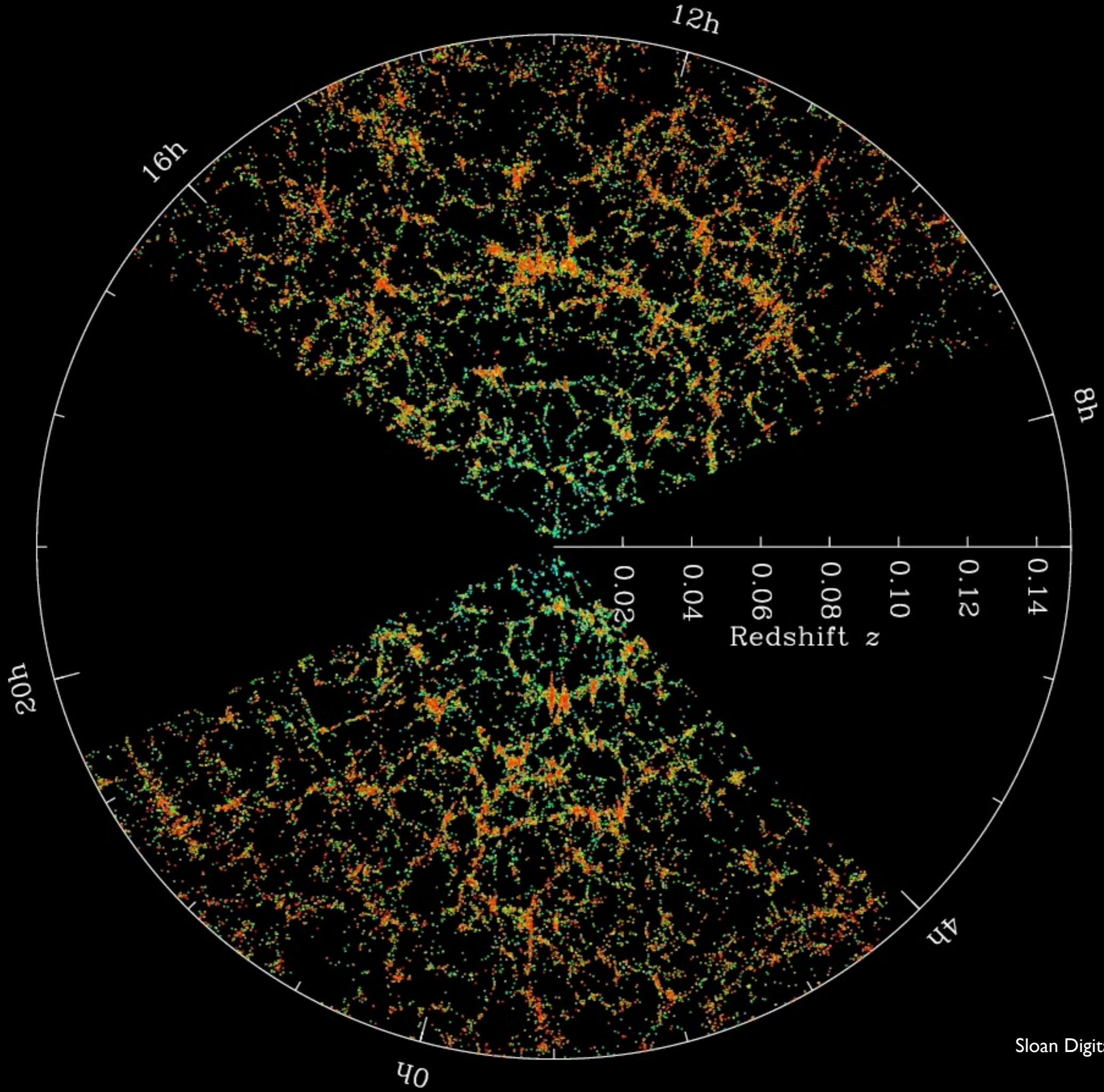


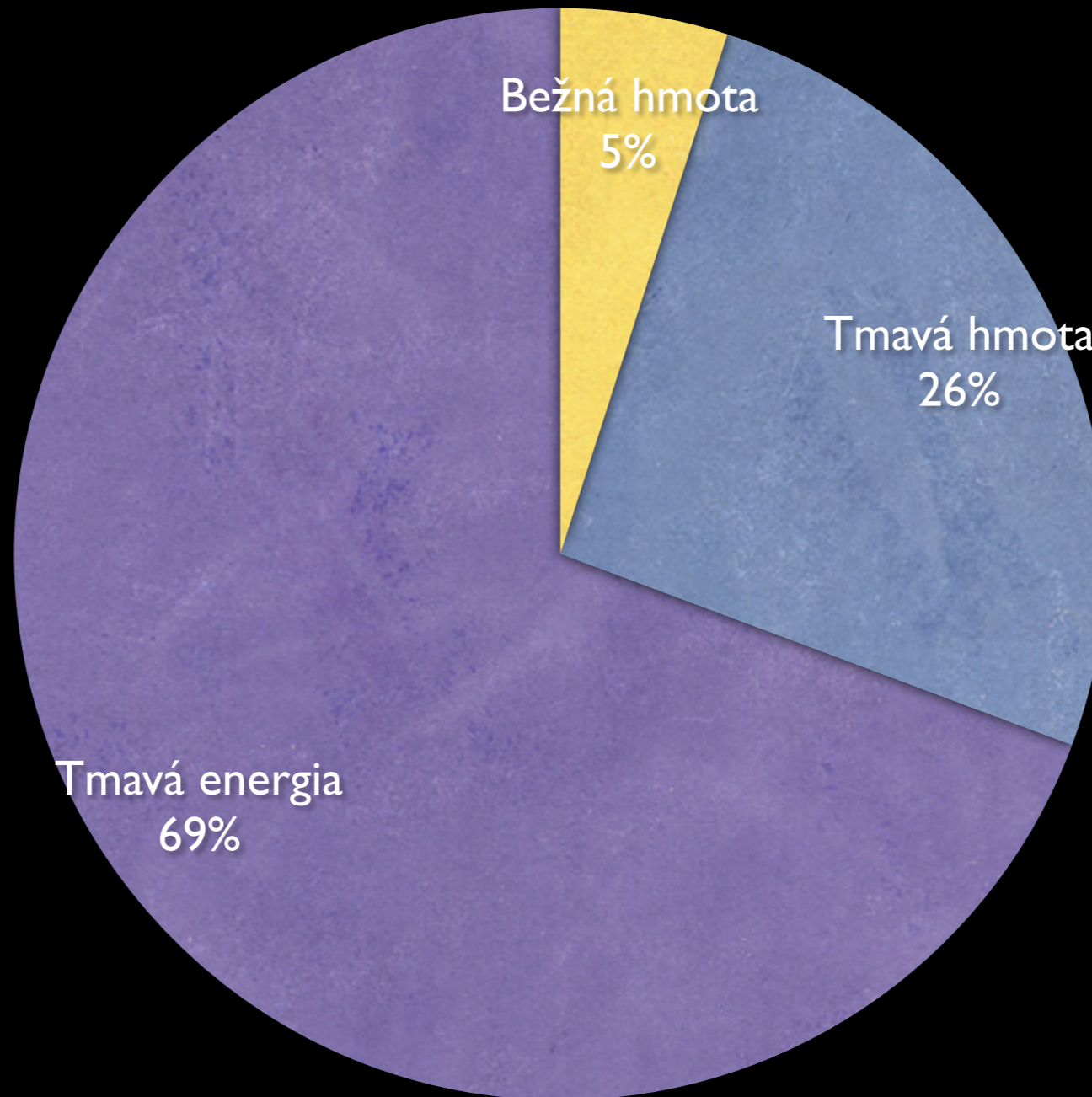


Size of Hubble eXtreme Deep Field on the Sky









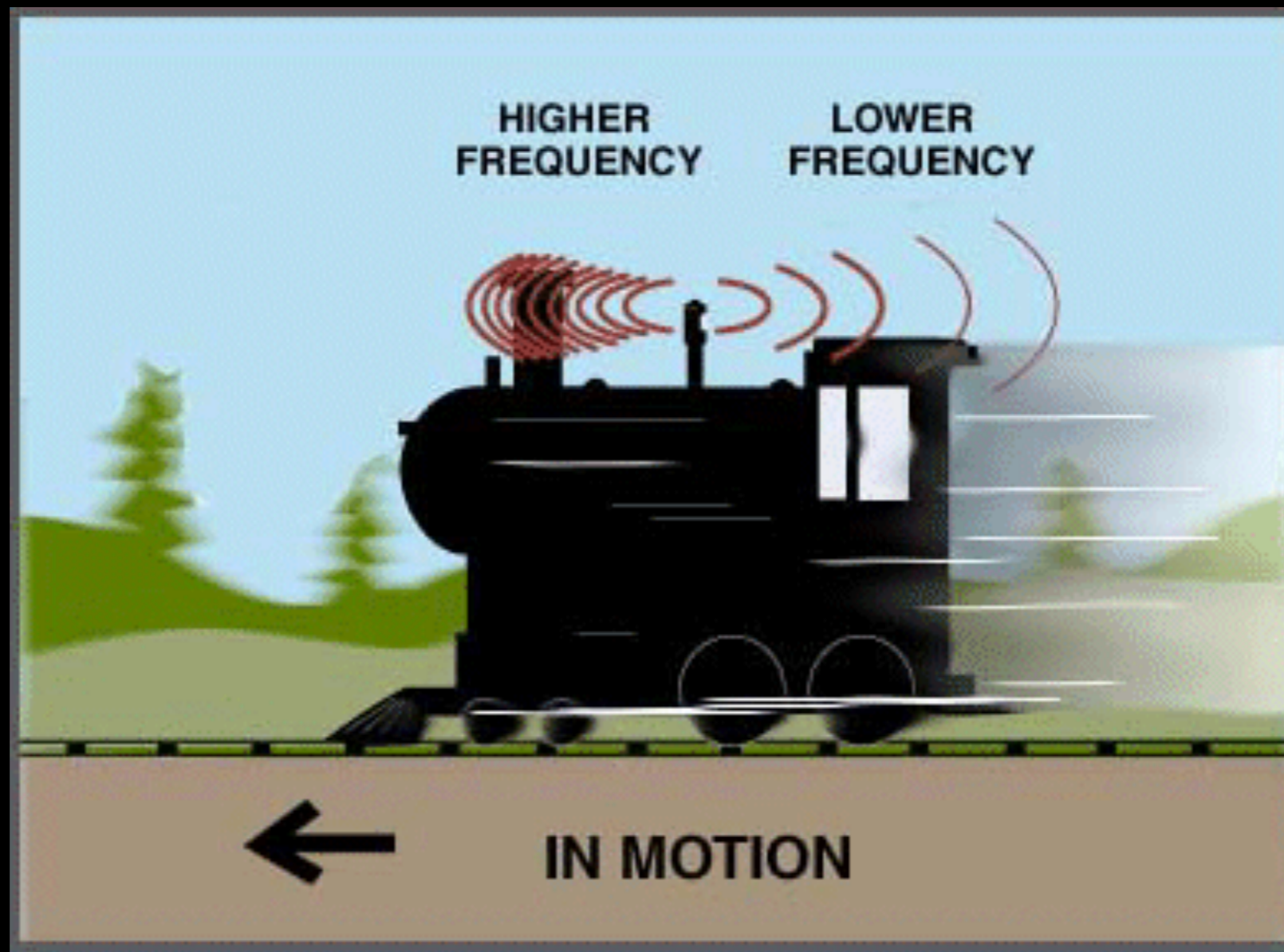


Fritz
Zwicky

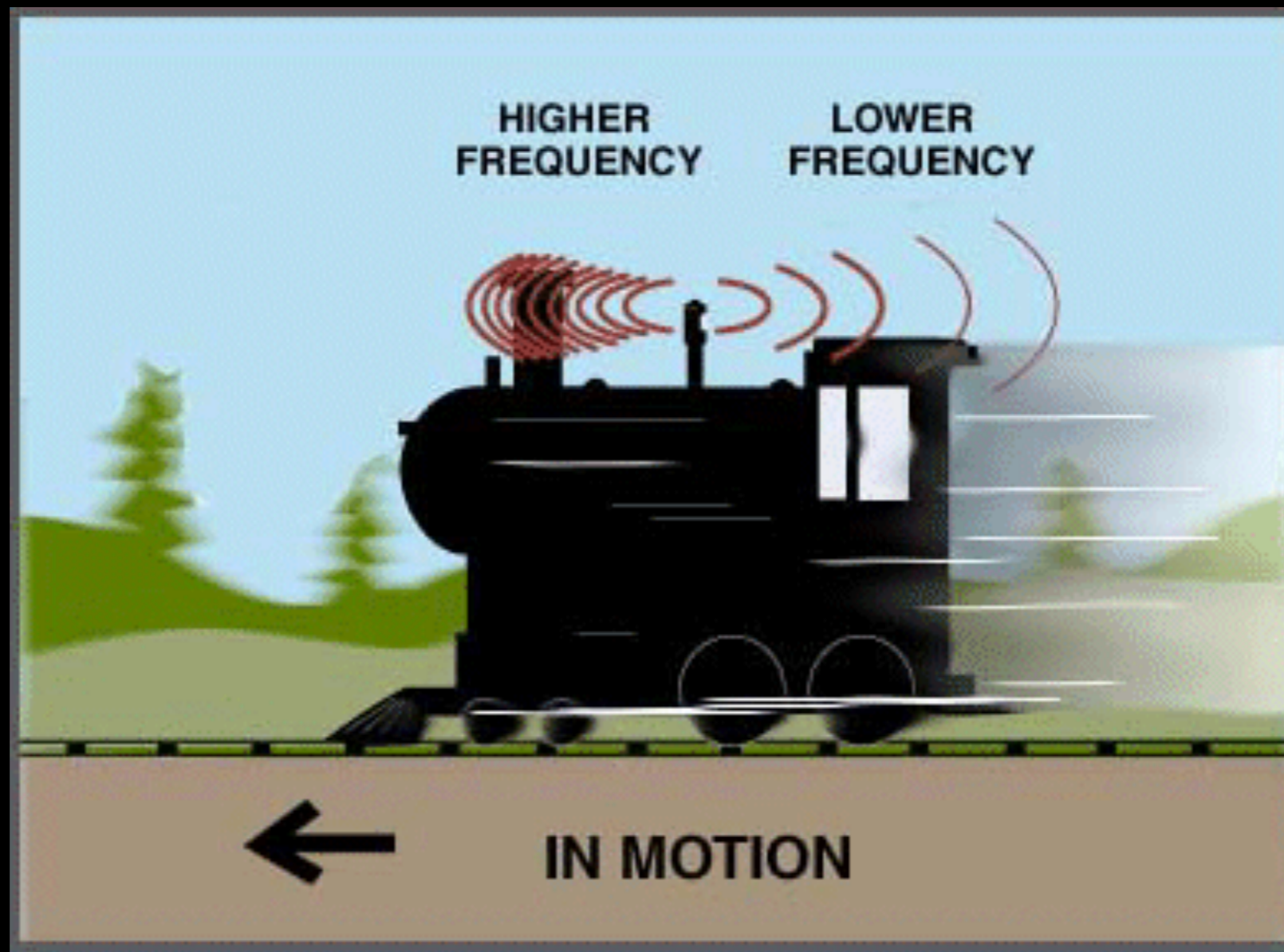
Kopa galaxií v suhvezdí
Vlasy Bereniky



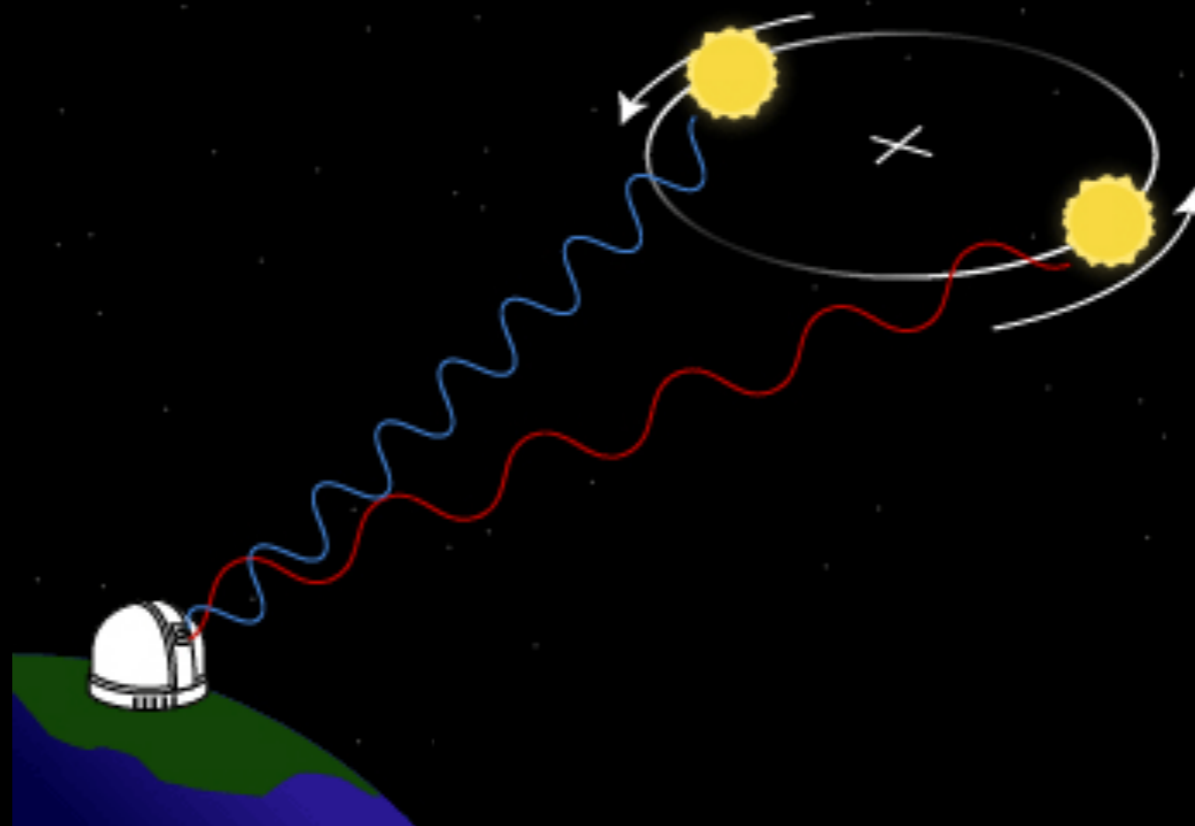
Dopplerov posun



Dopplerov posun



Dopplerov posun





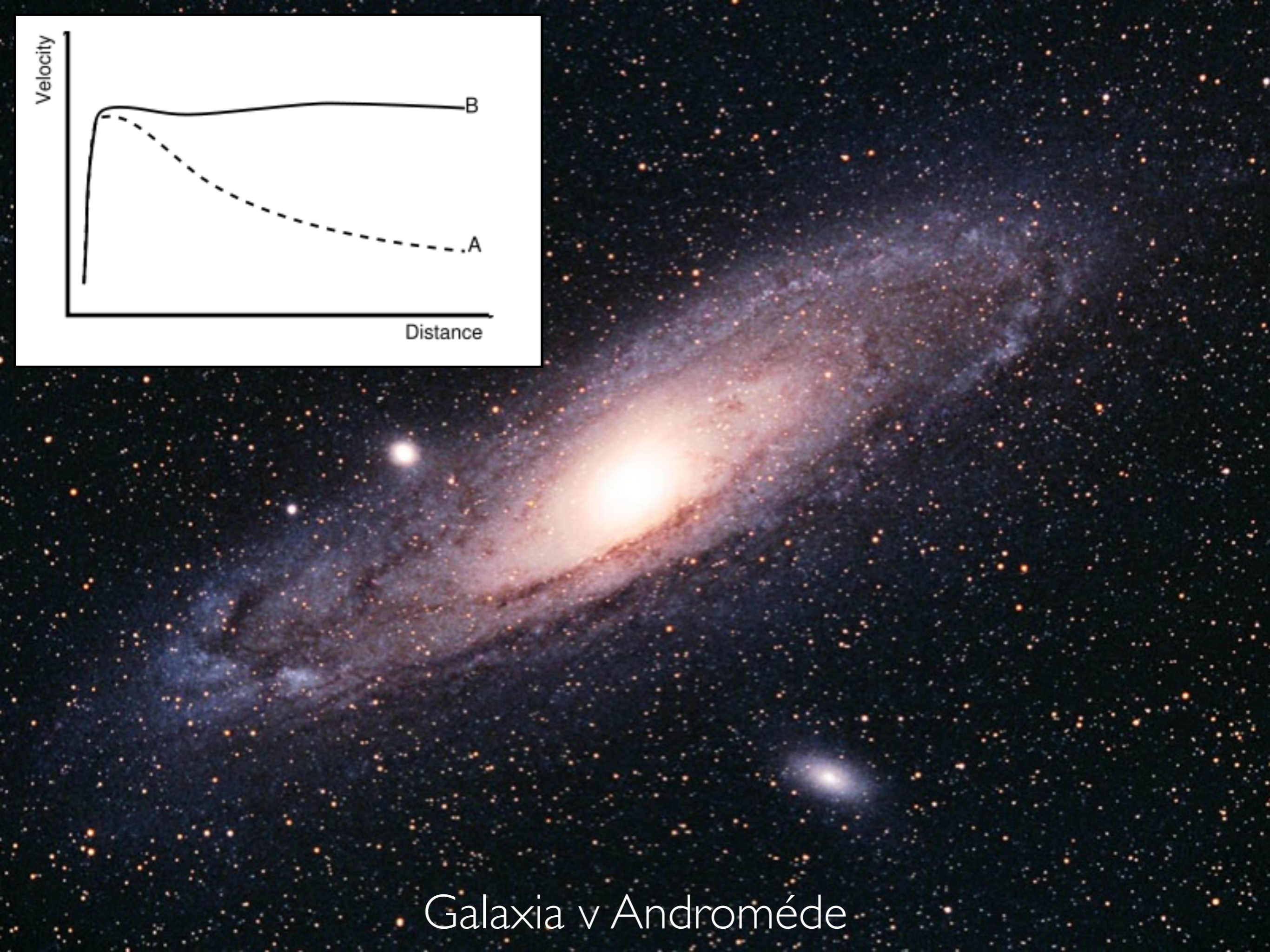
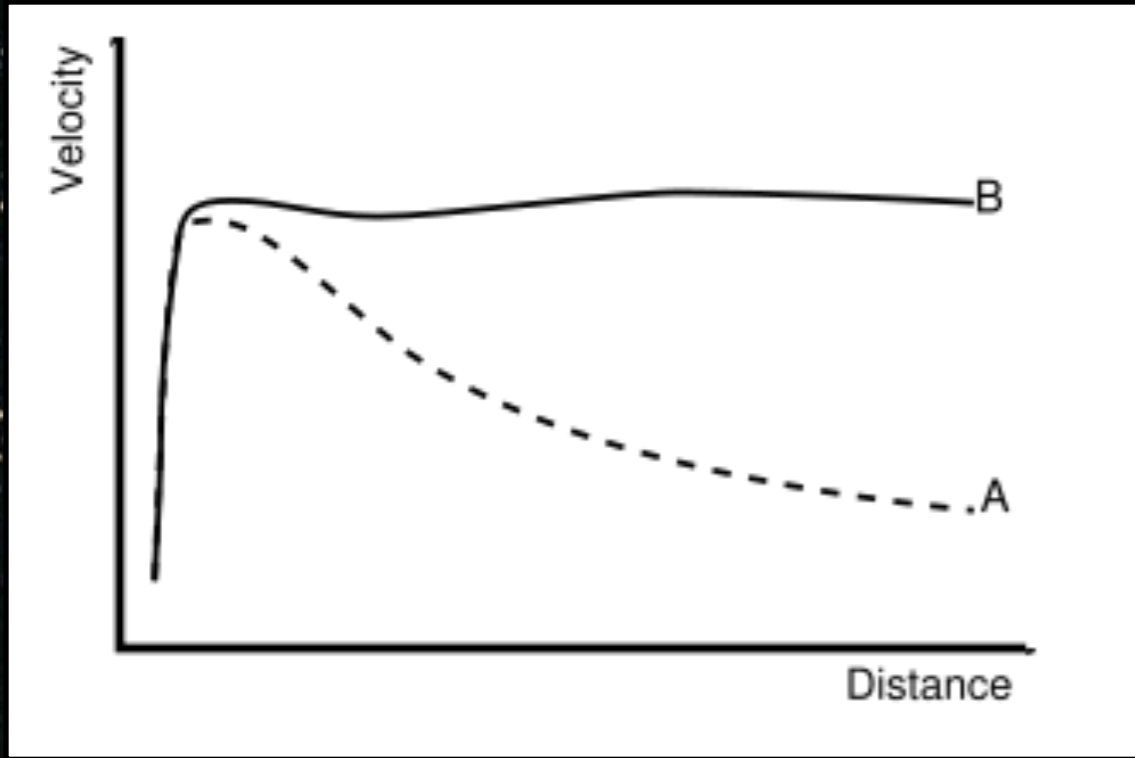
Fritz
Zwicky

Kopa galaxií v suhvezdí
Vlasy Bereniky

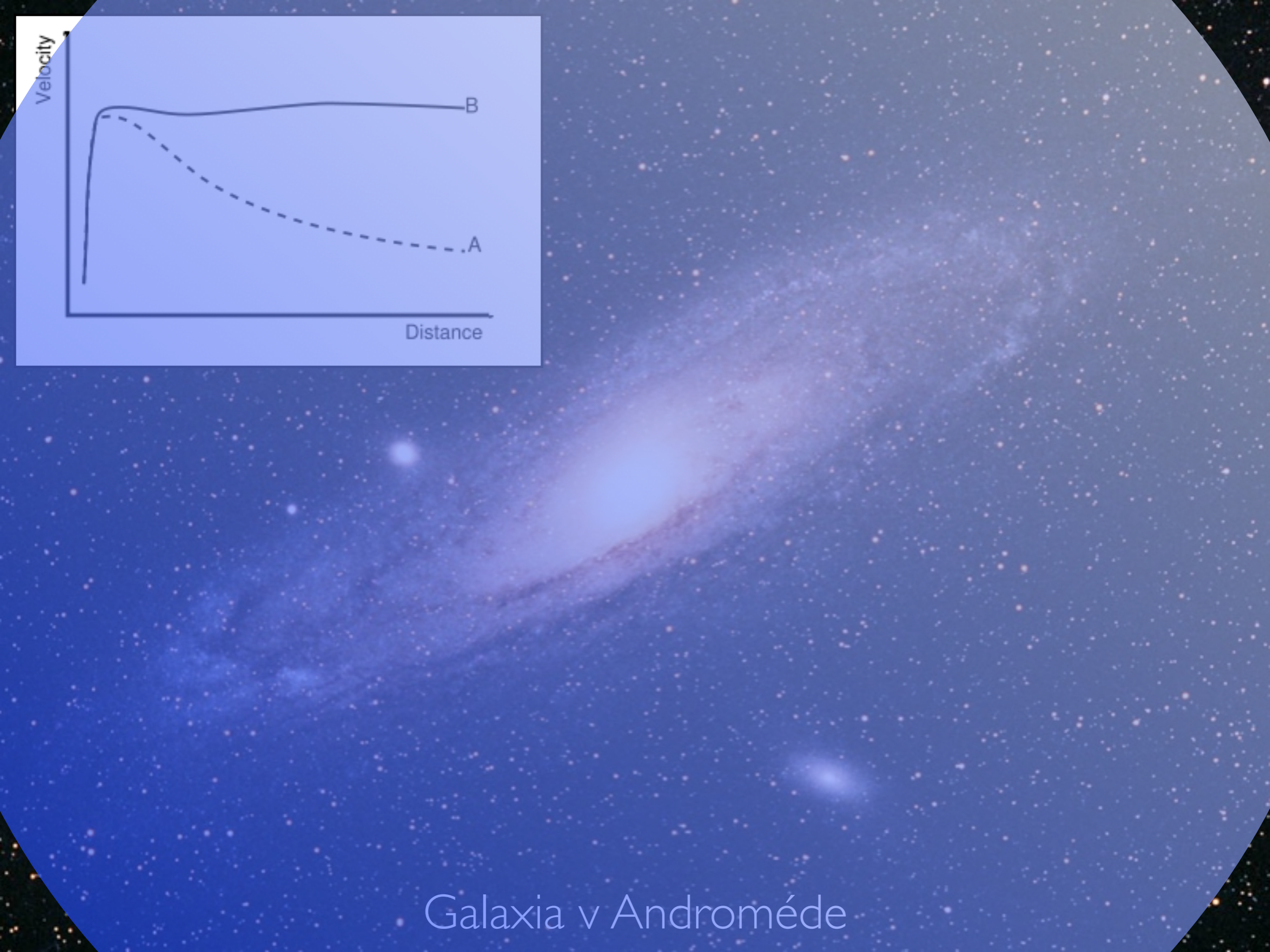
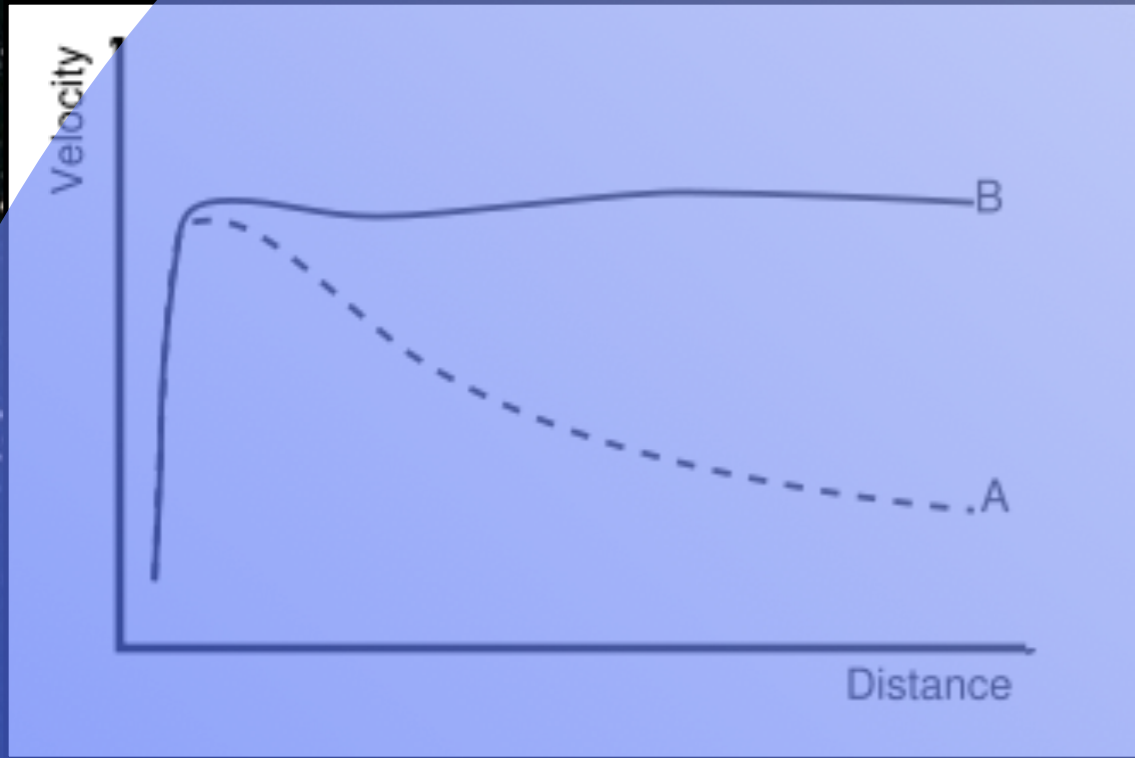




Galaxia v Androméde

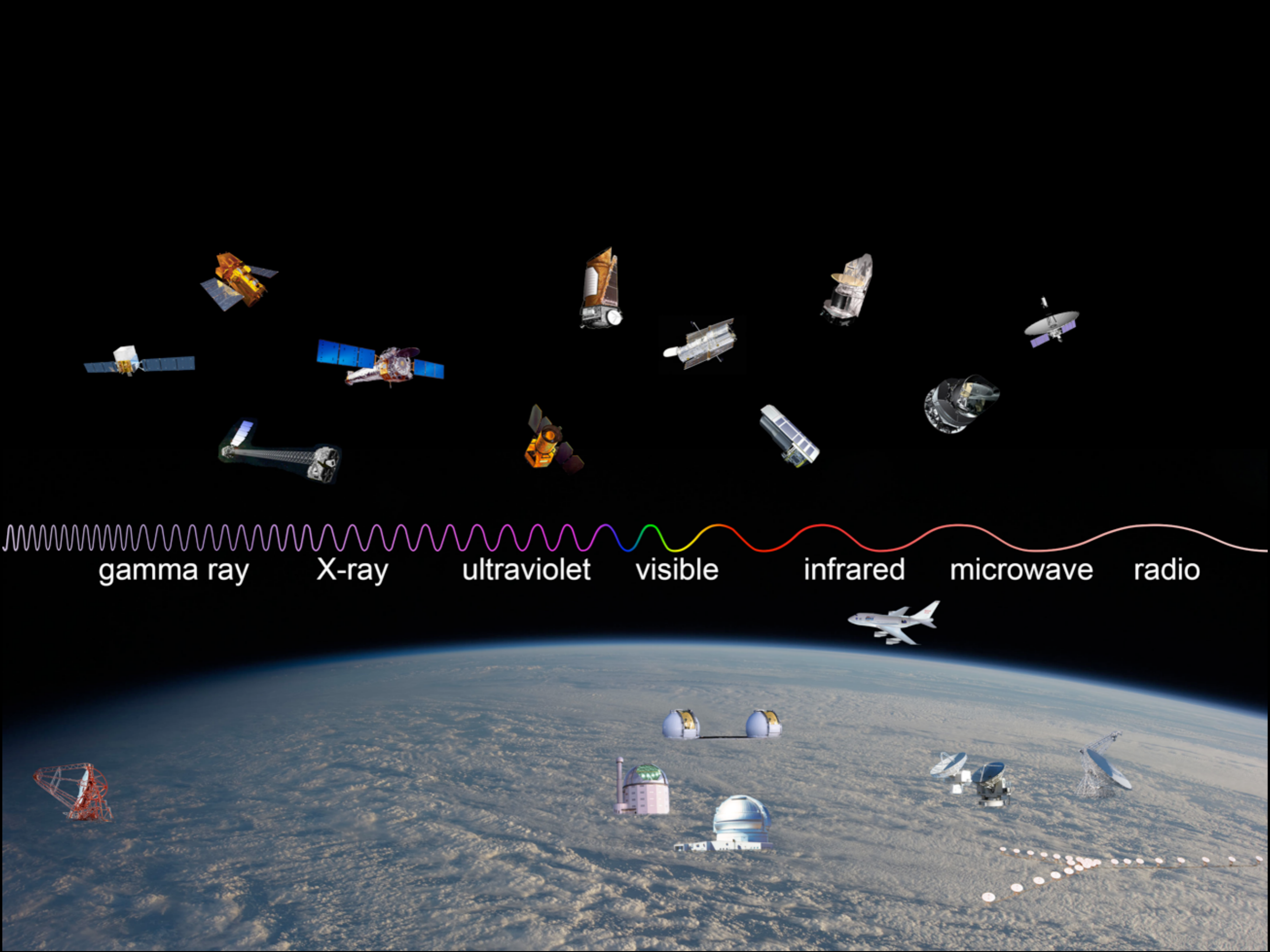


Galaxia v Androméde



Galaxia v Androméde





gamma ray

X-ray

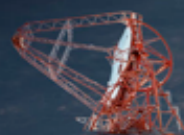
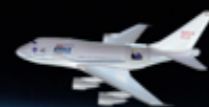
ultraviolet

visible

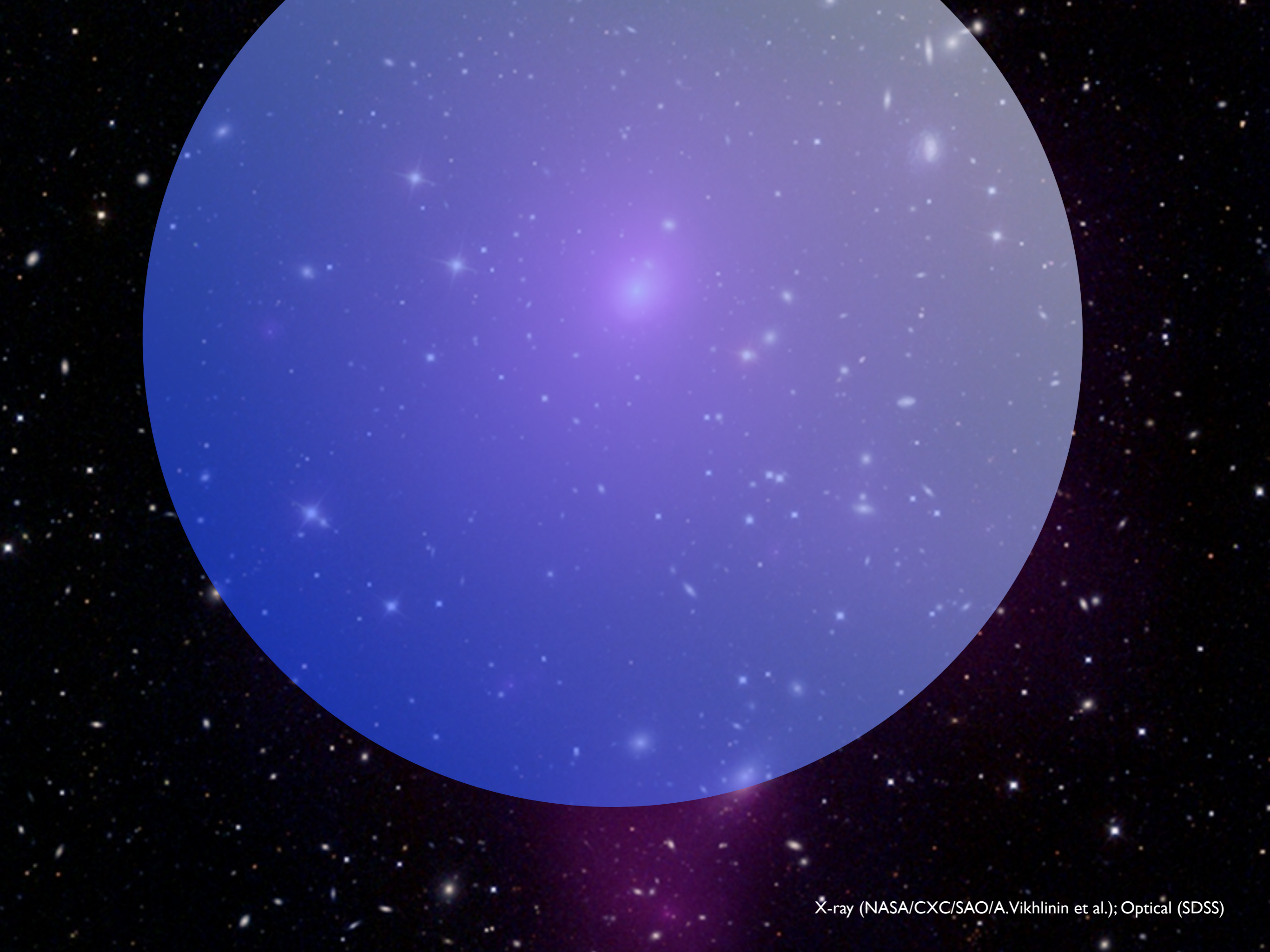
infrared

microwave

radio

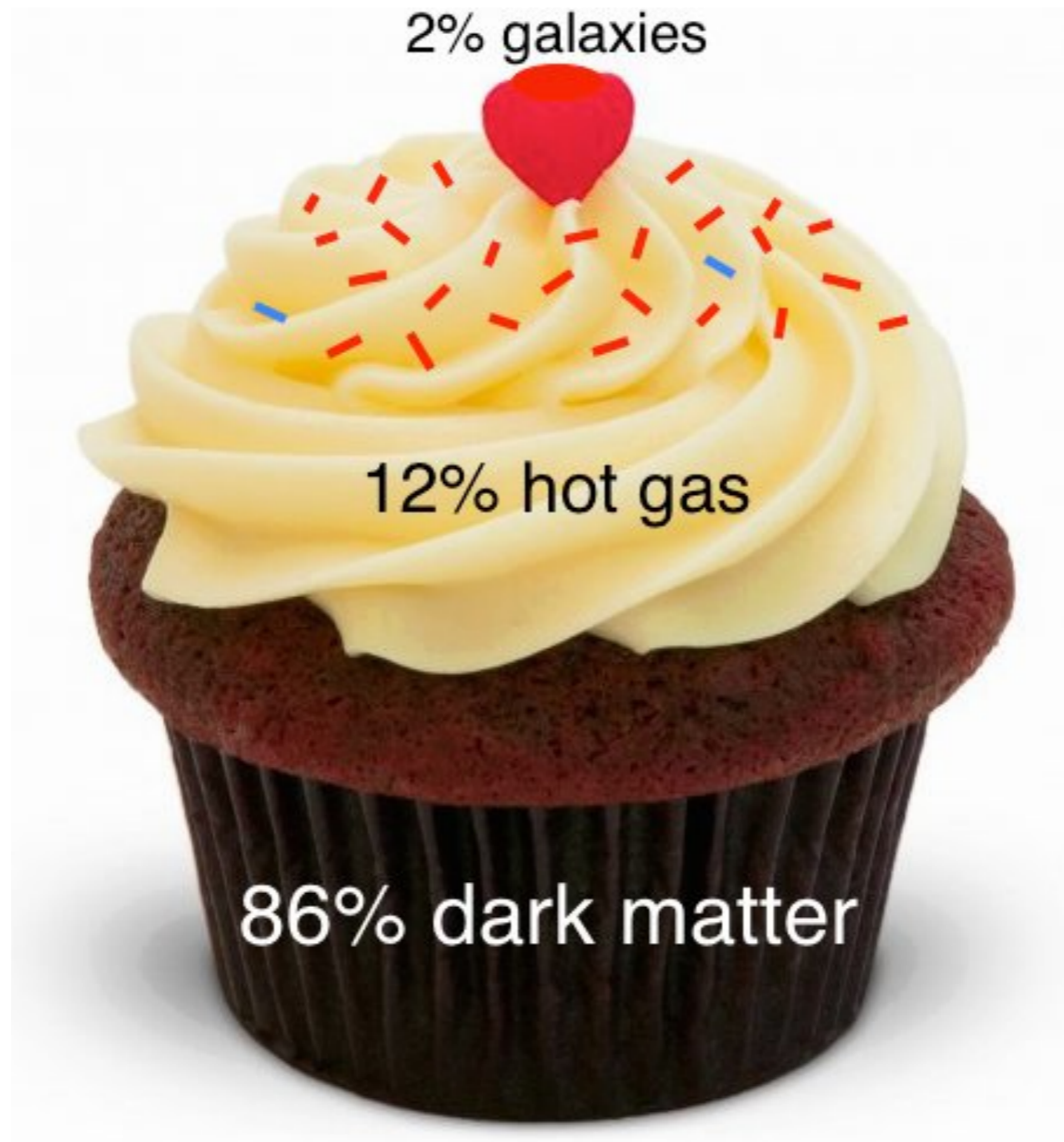






X-ray (NASA/CXC/SAO/A.Vikhlinin et al.); Optical (SDSS)

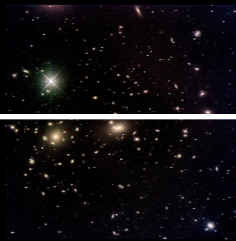
CLUSTERS OF GALAXIES AS CUPCAKES

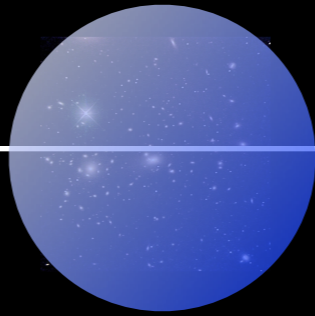
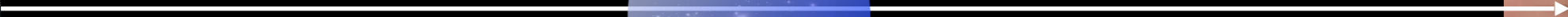


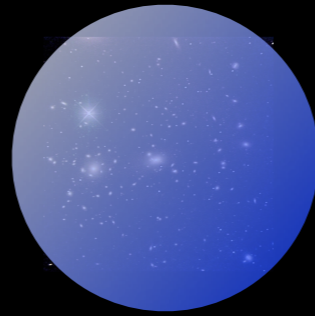


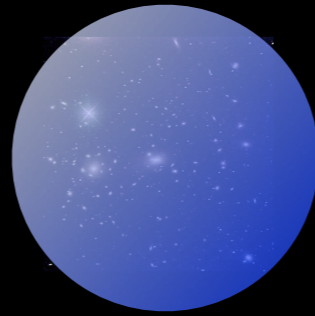
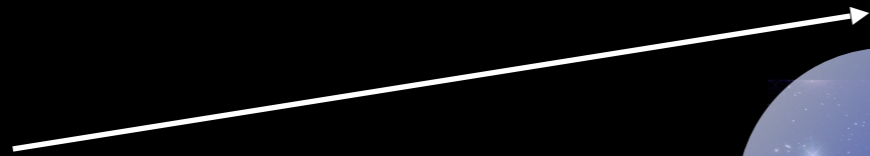


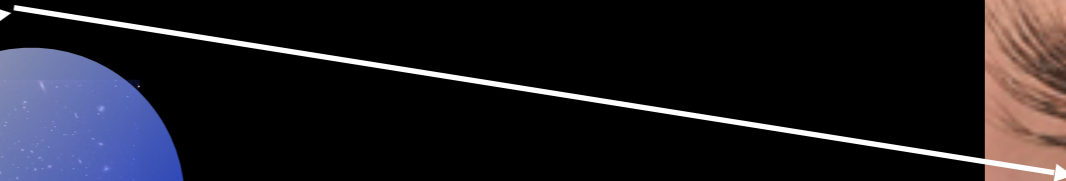
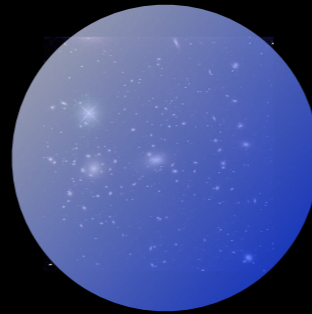
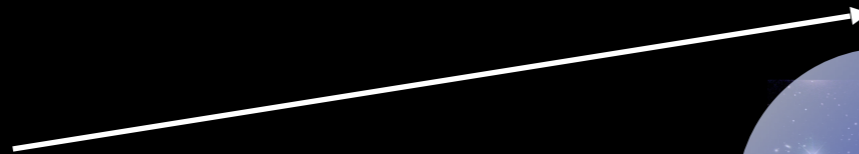


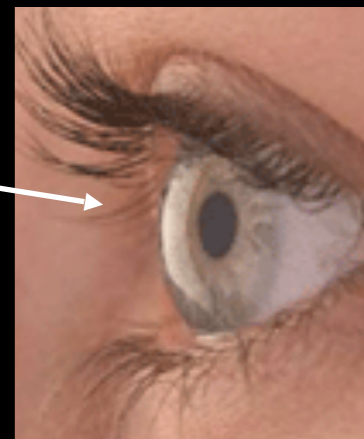
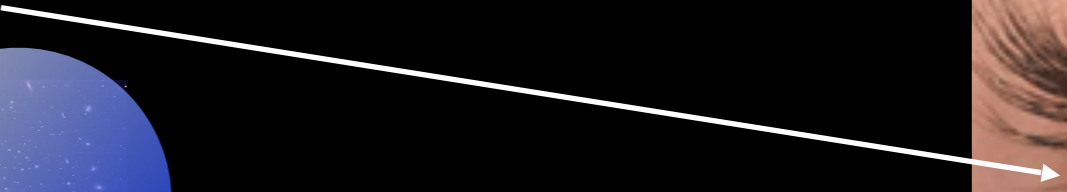
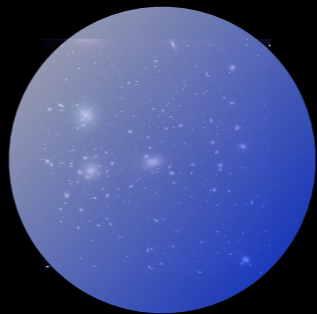
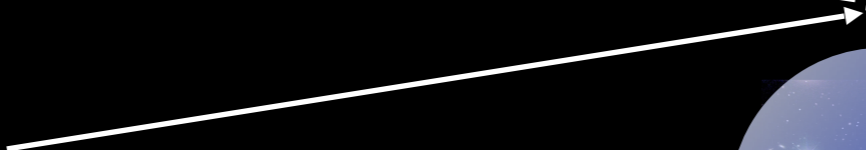
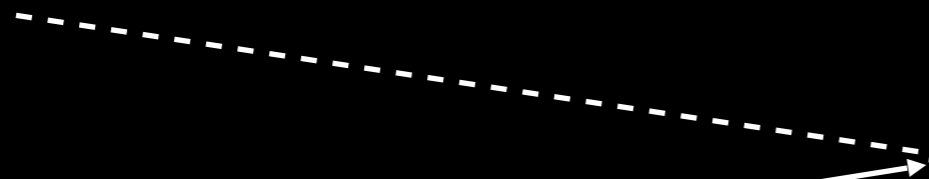


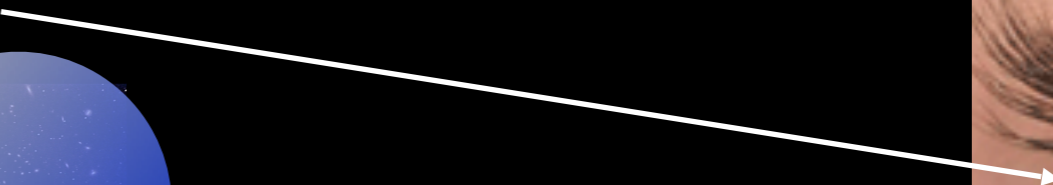
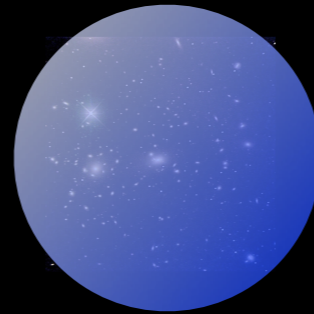
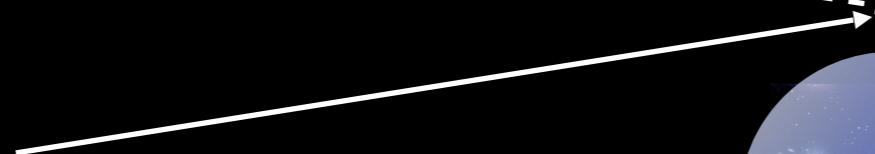
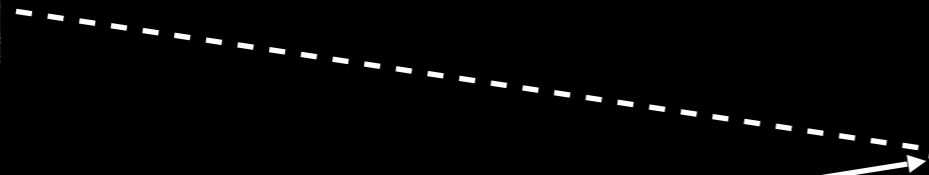


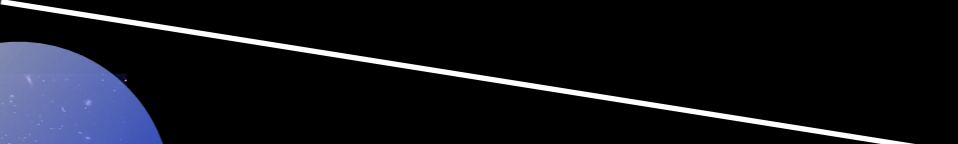
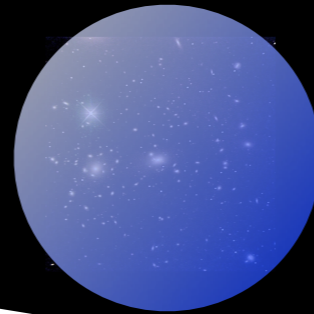
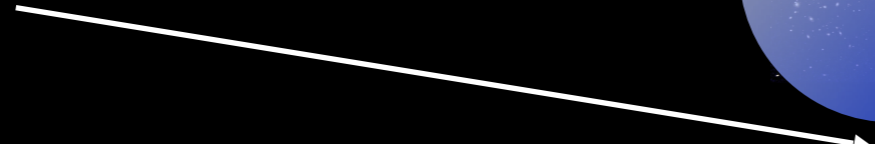
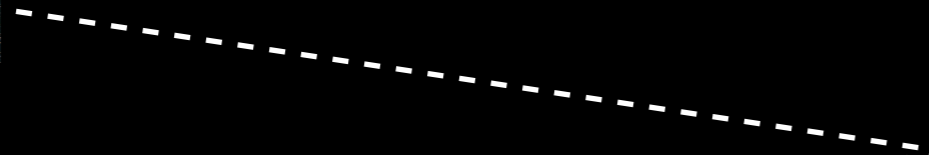


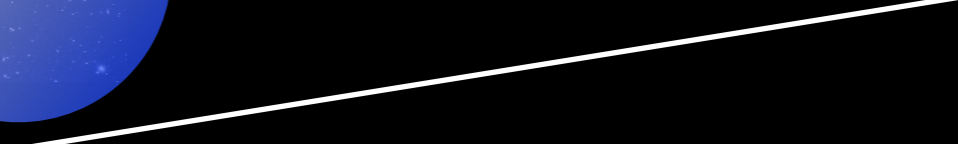
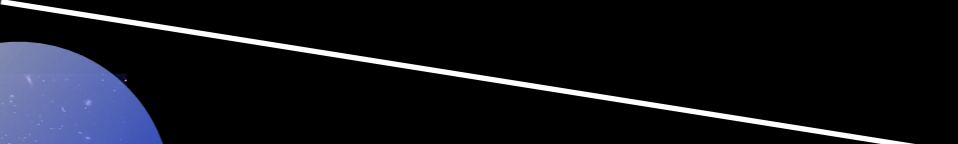
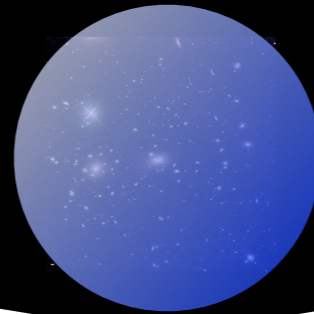
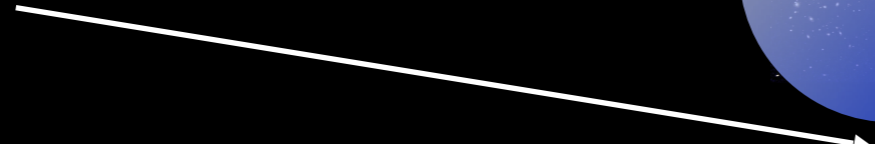
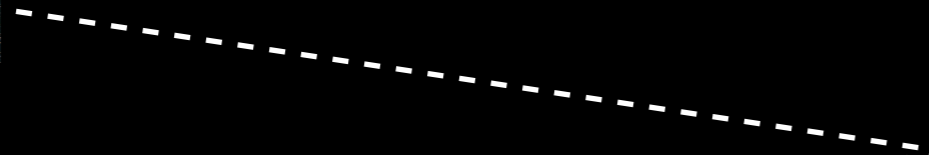


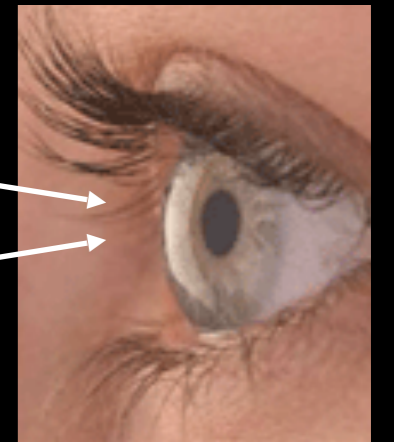
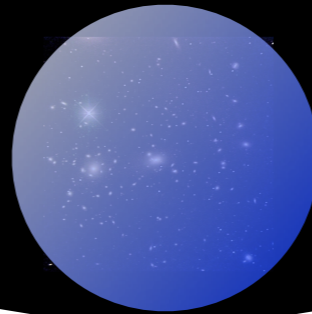
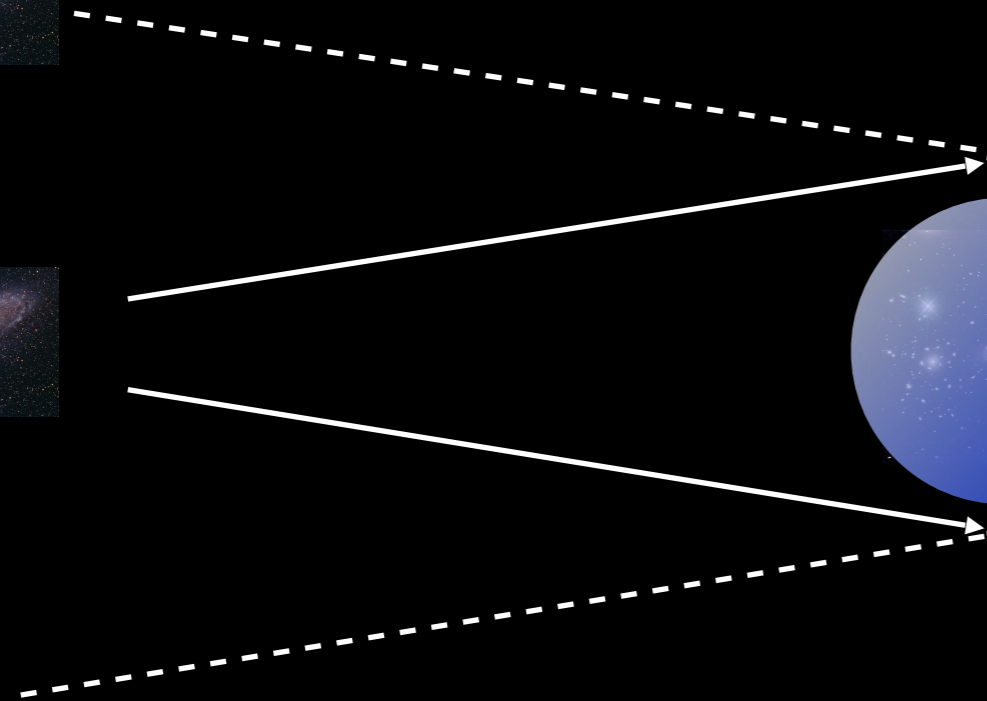


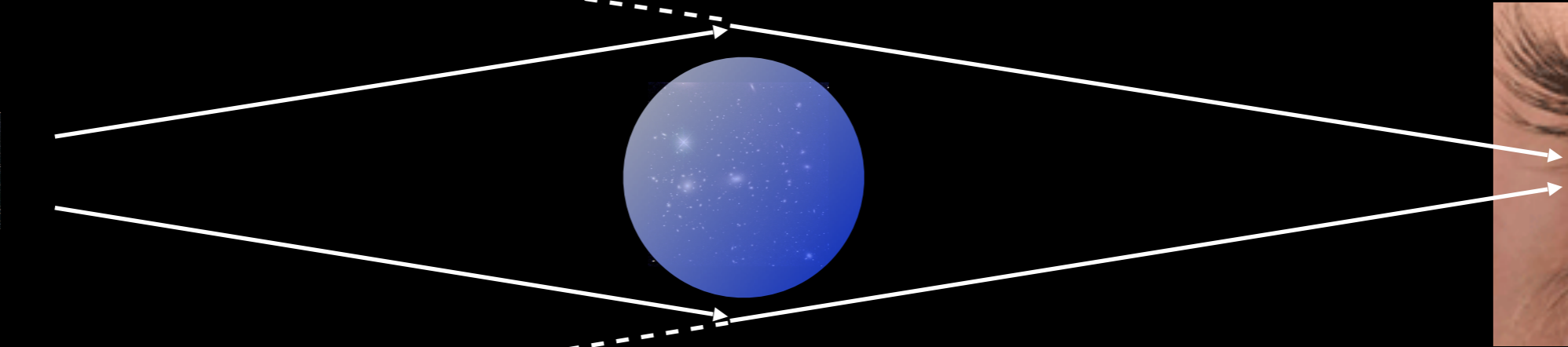
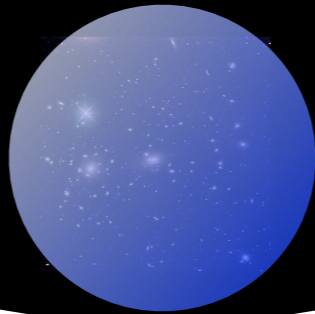
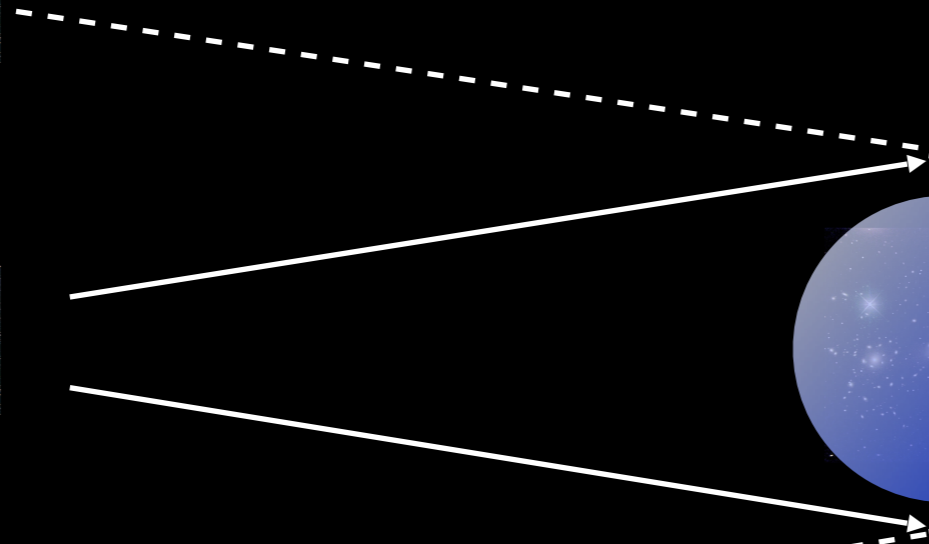






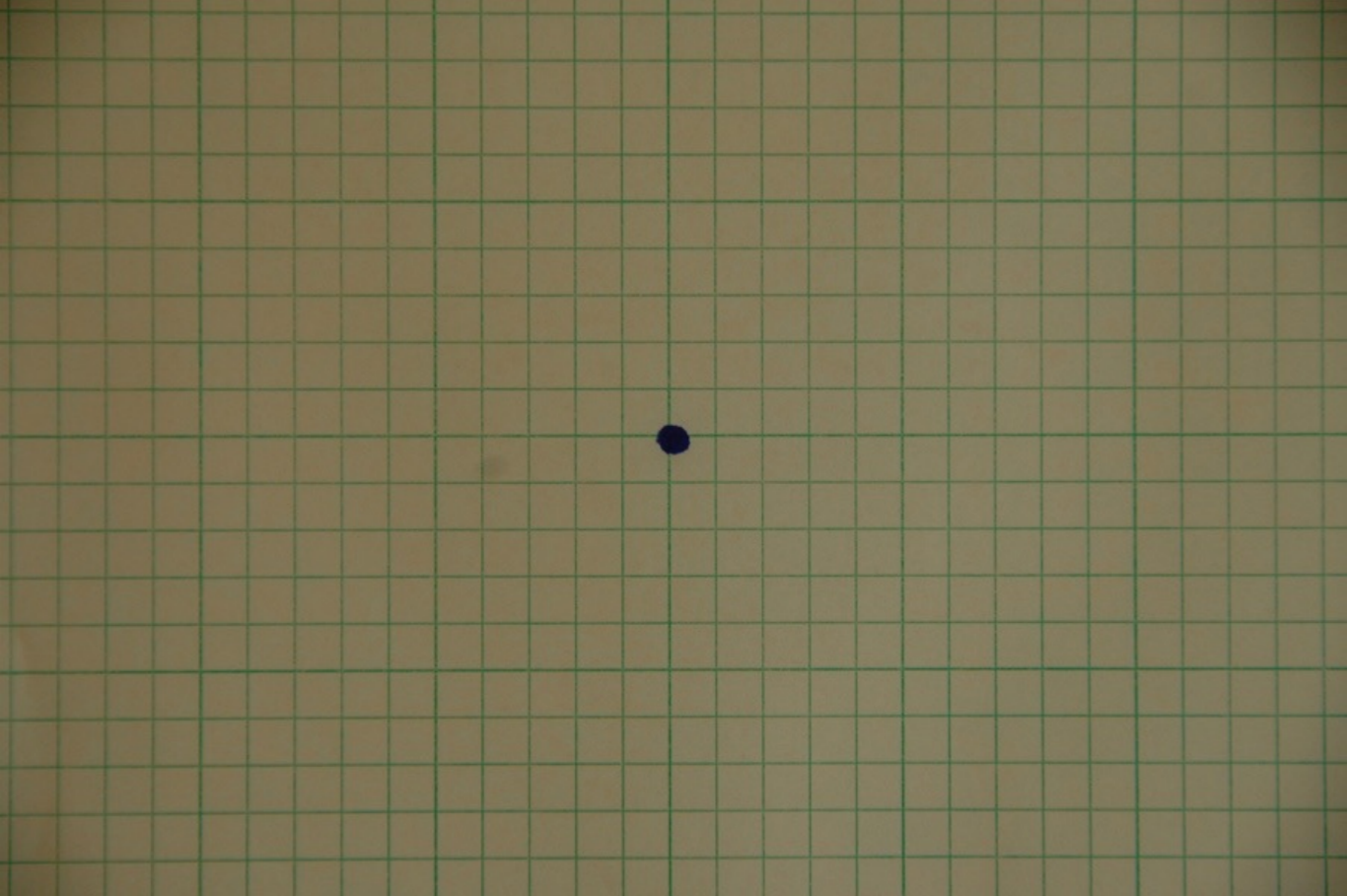




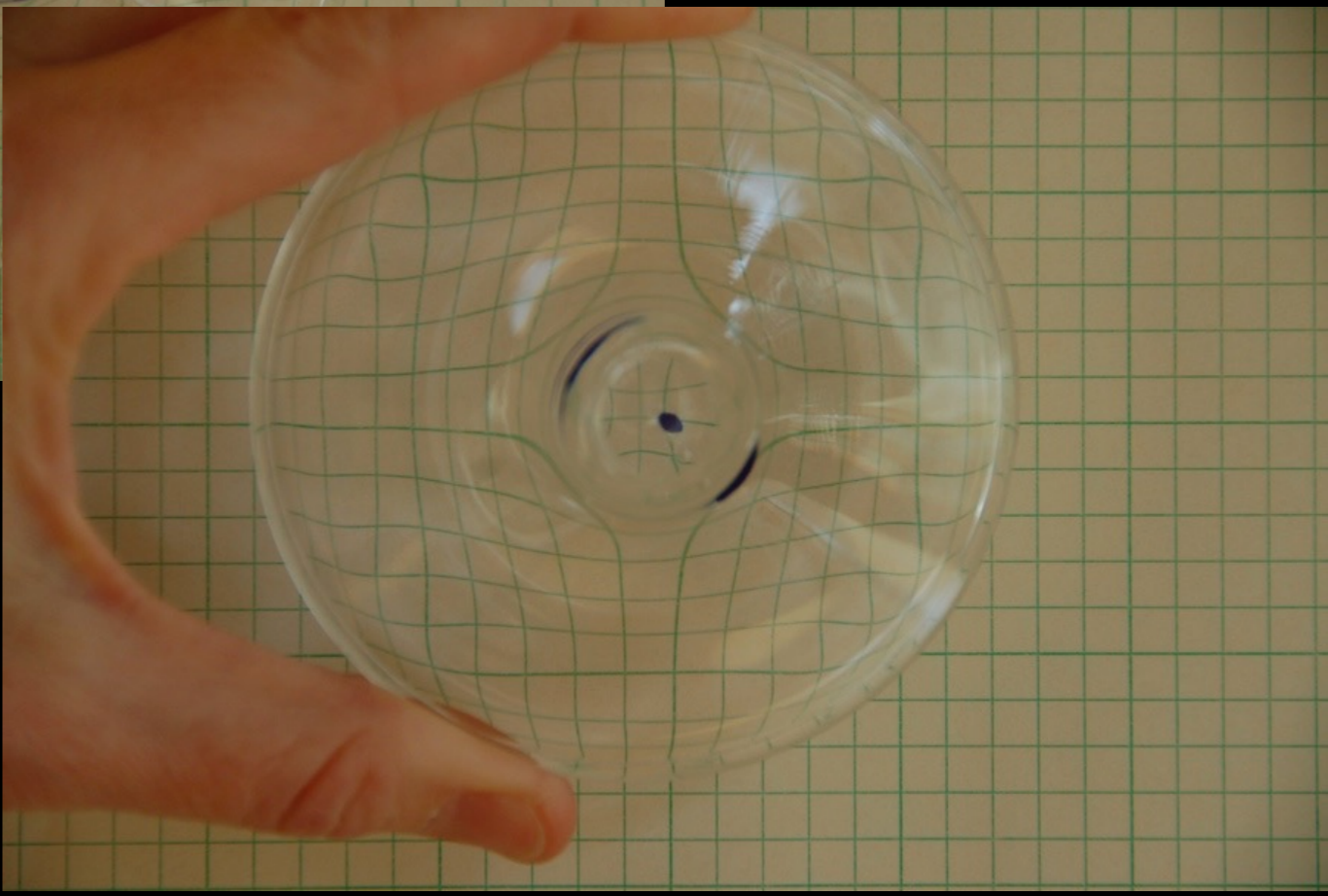
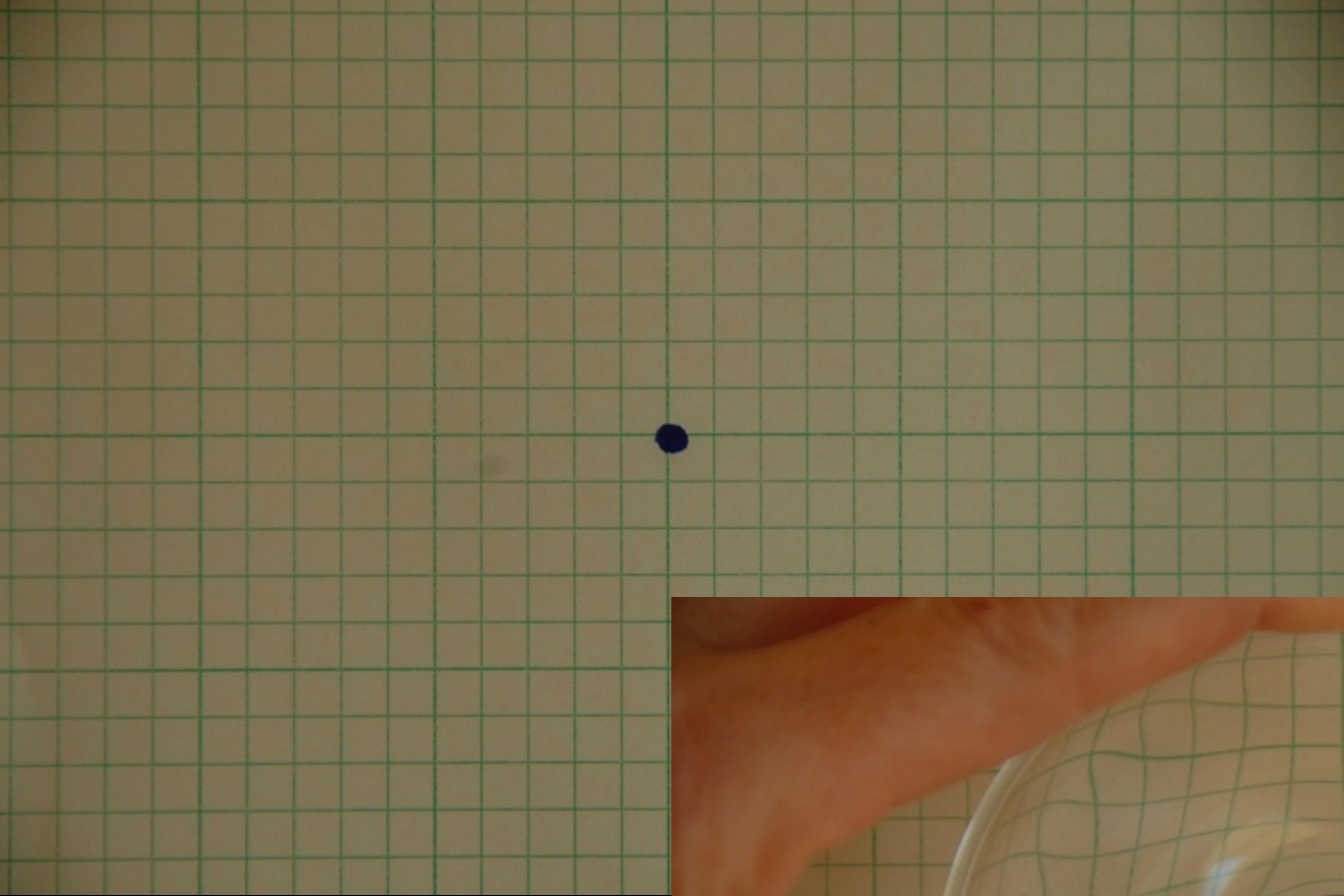


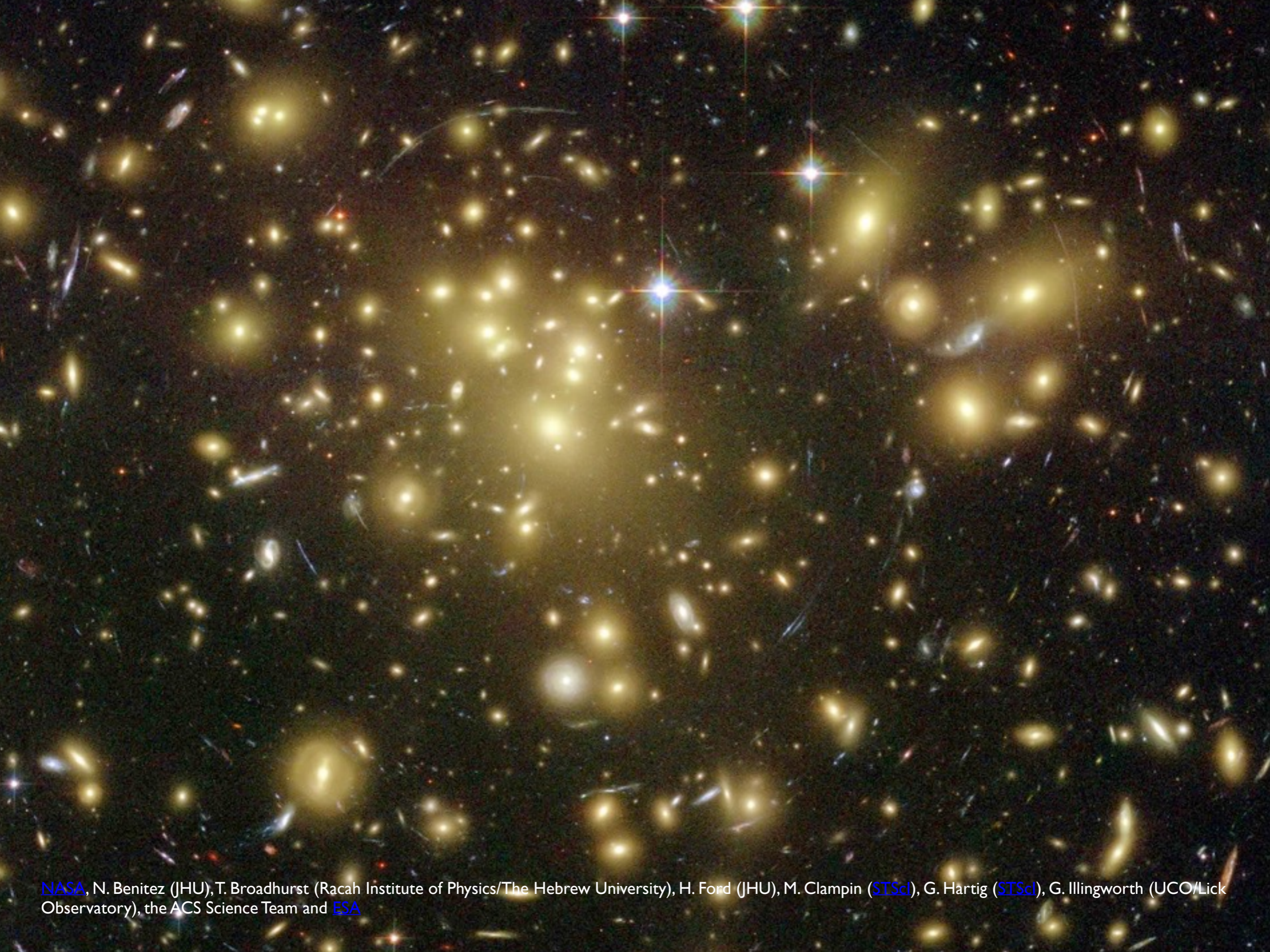




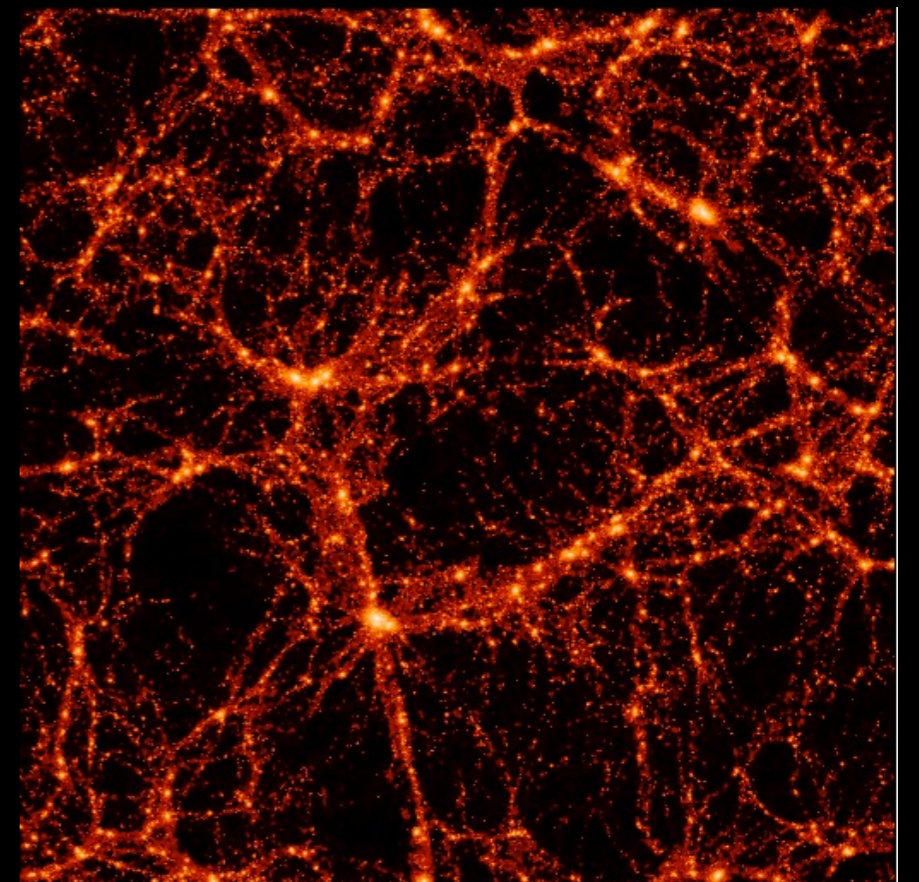
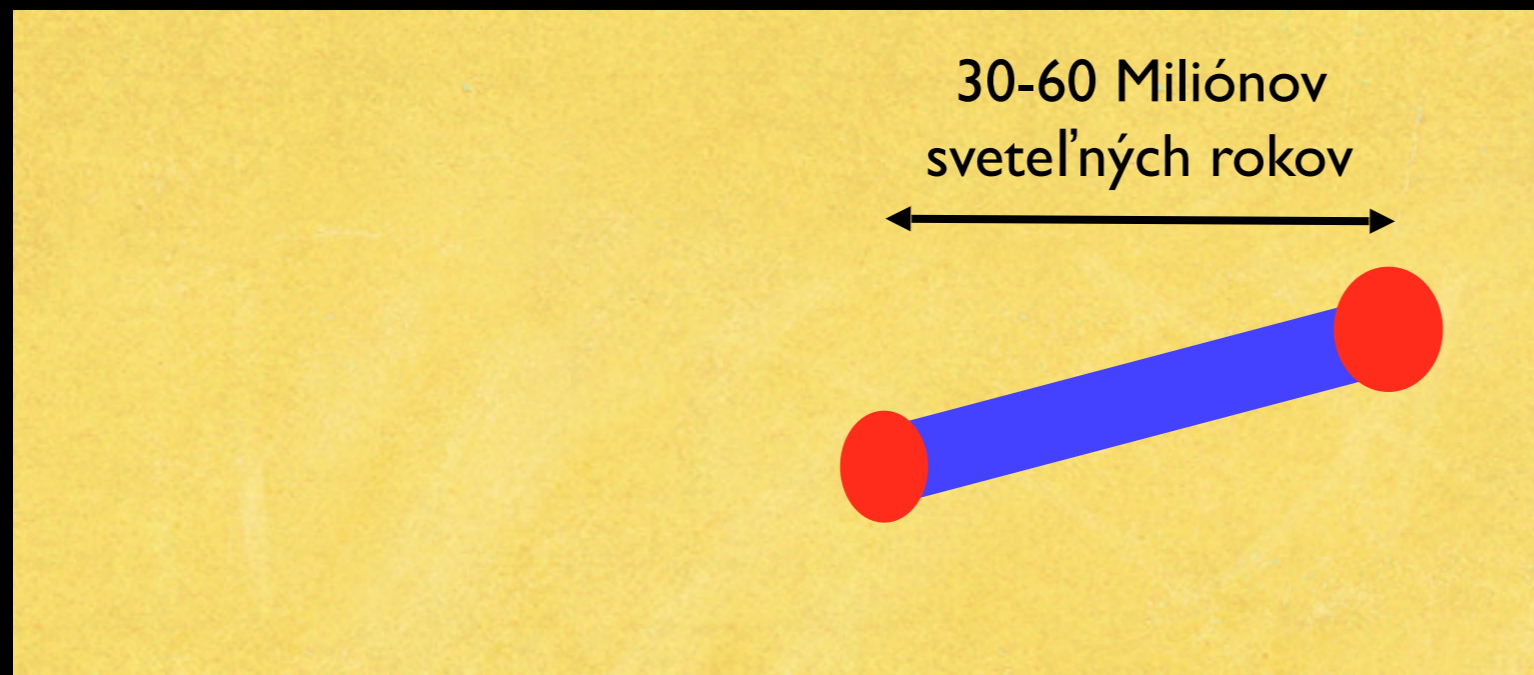




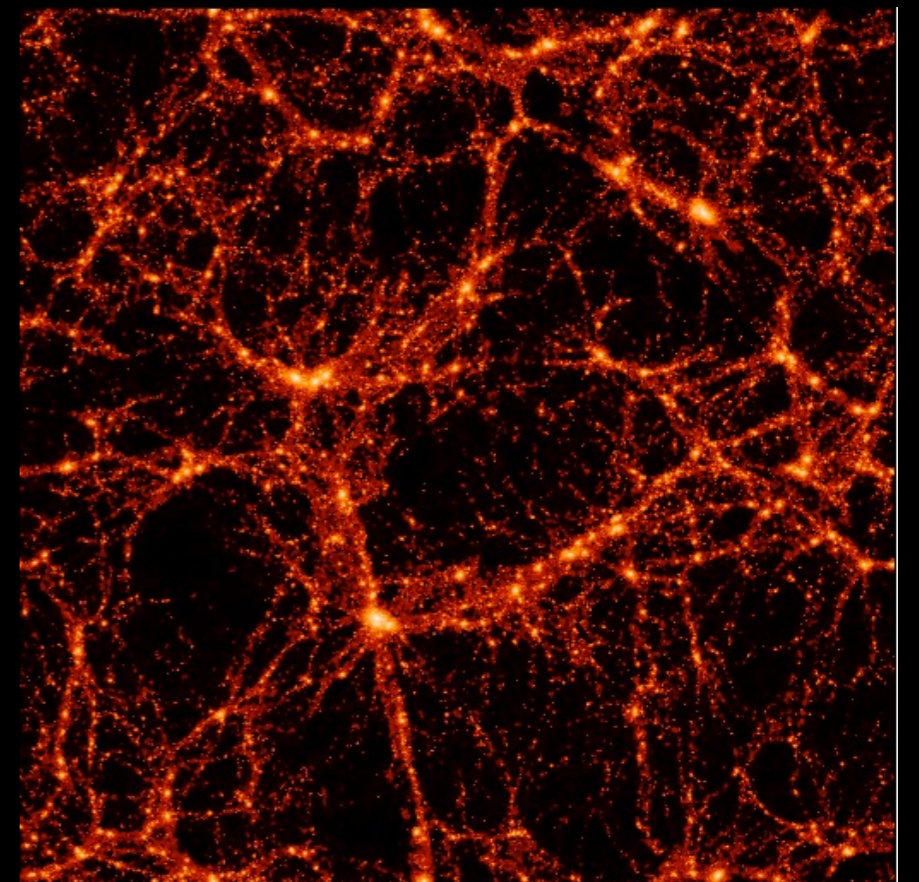
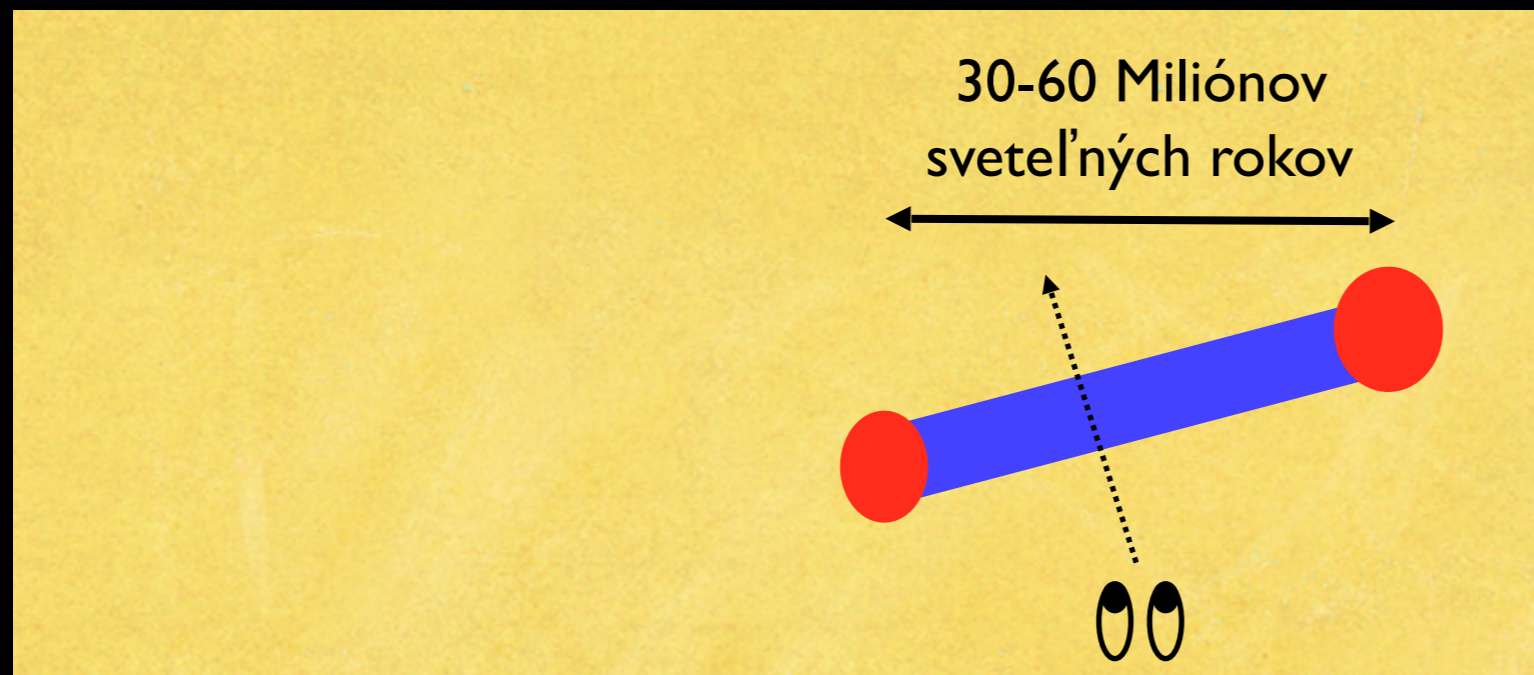




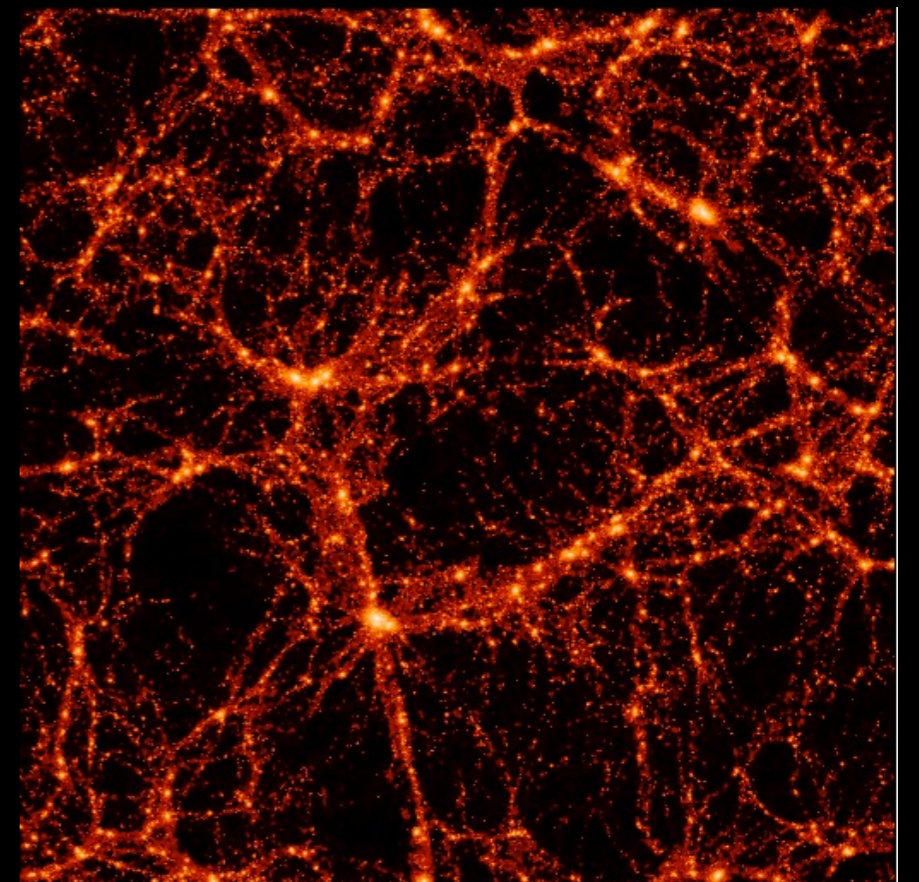
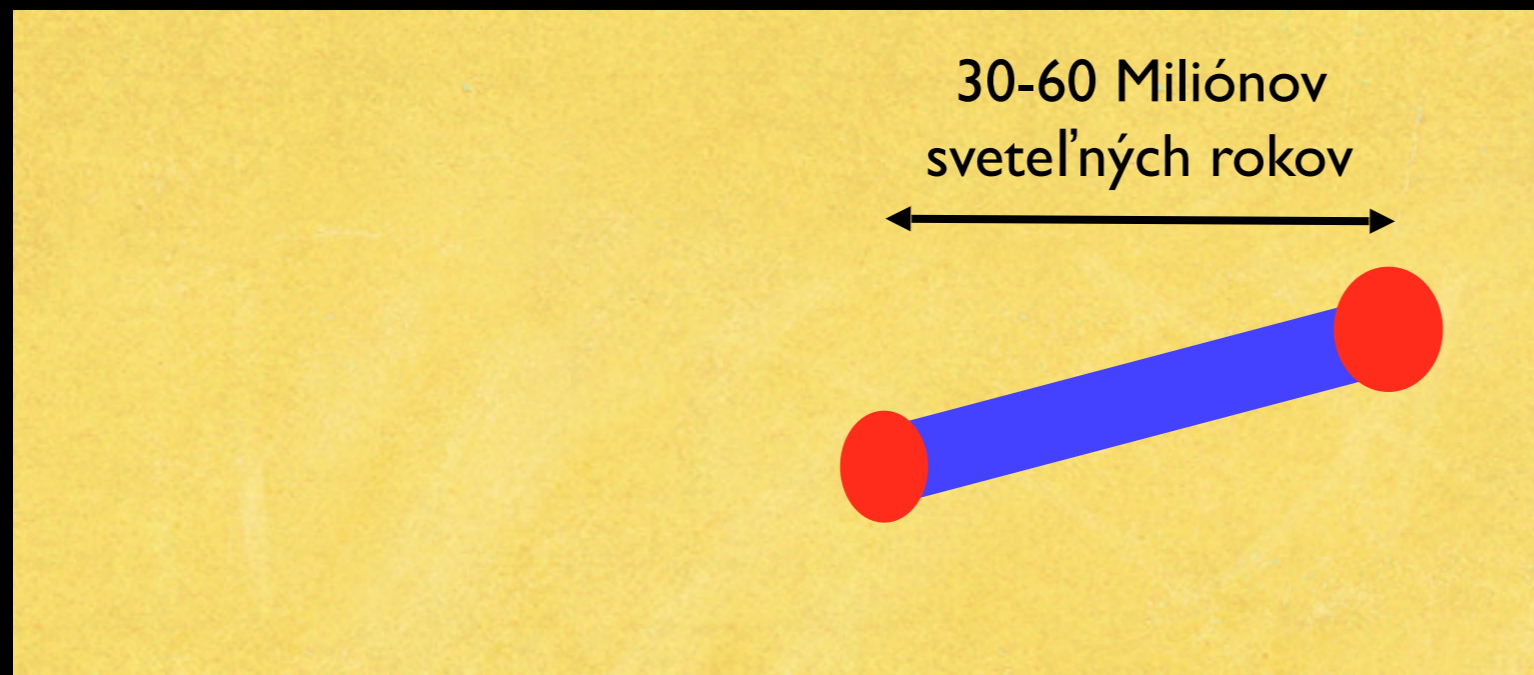
Chýbajúca normálna hmota



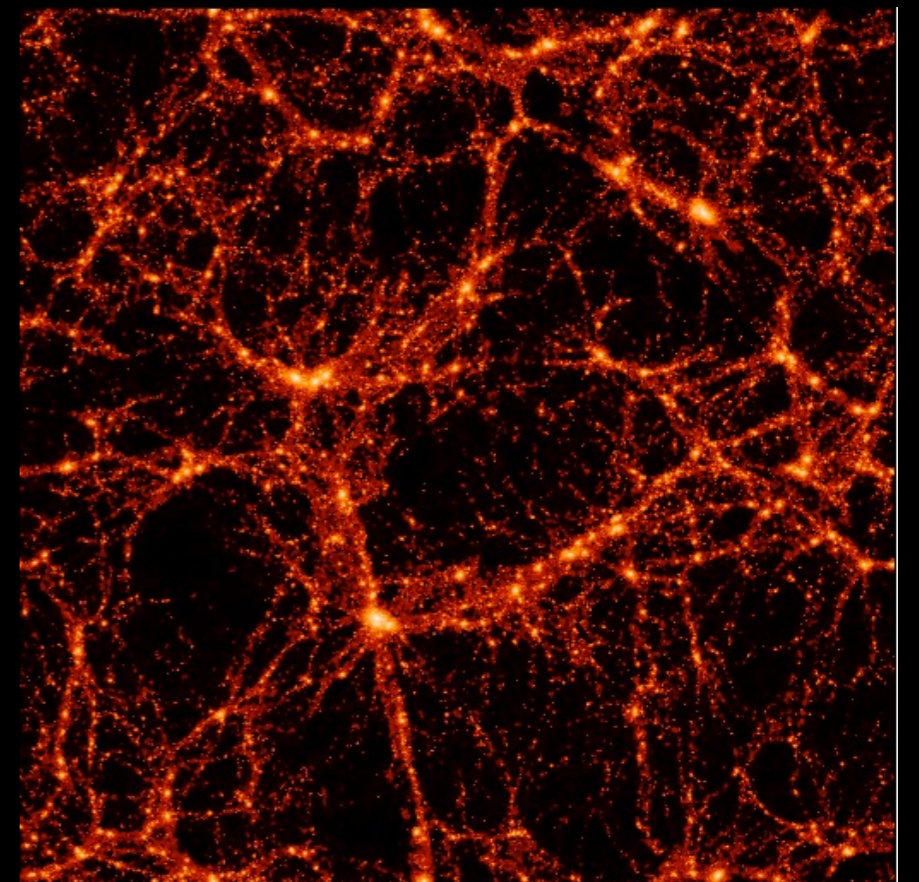
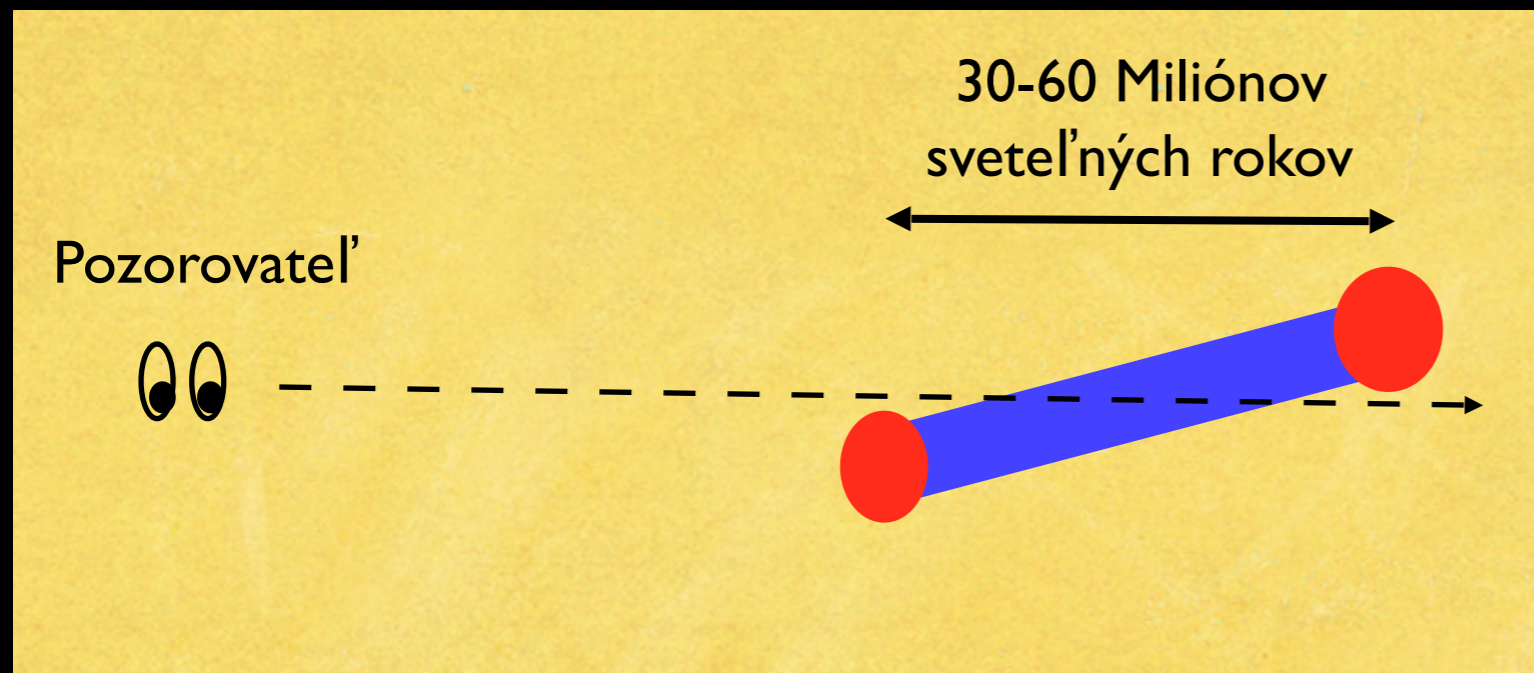
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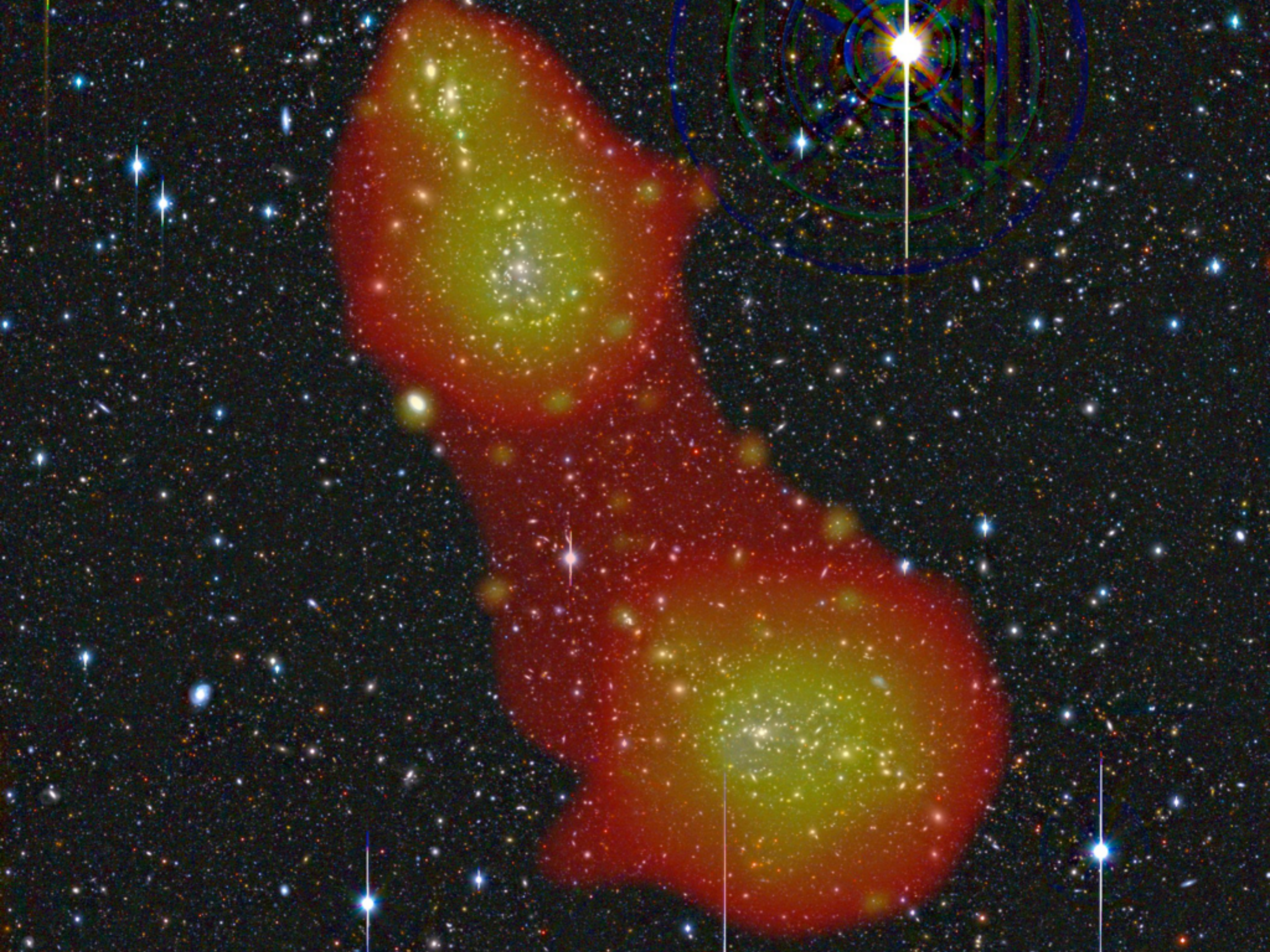


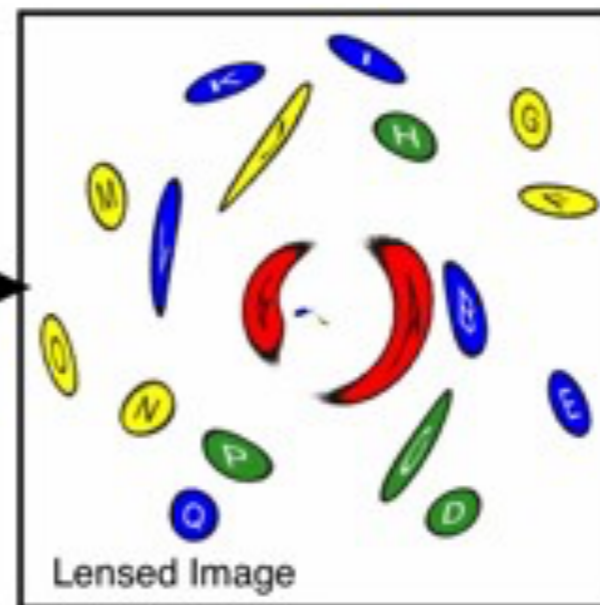
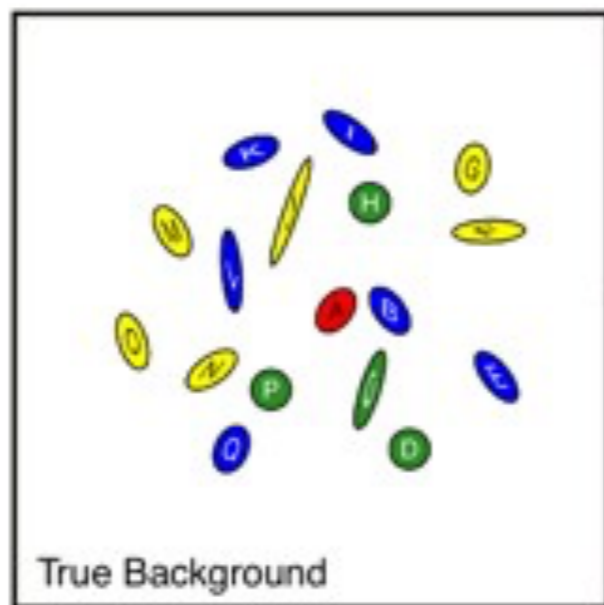
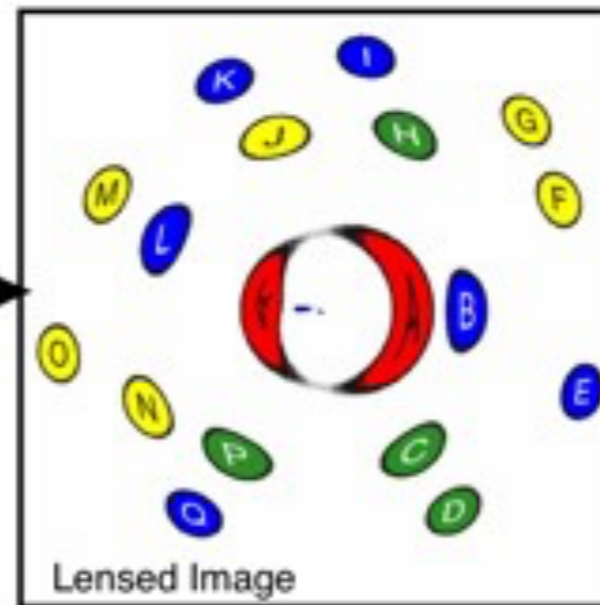
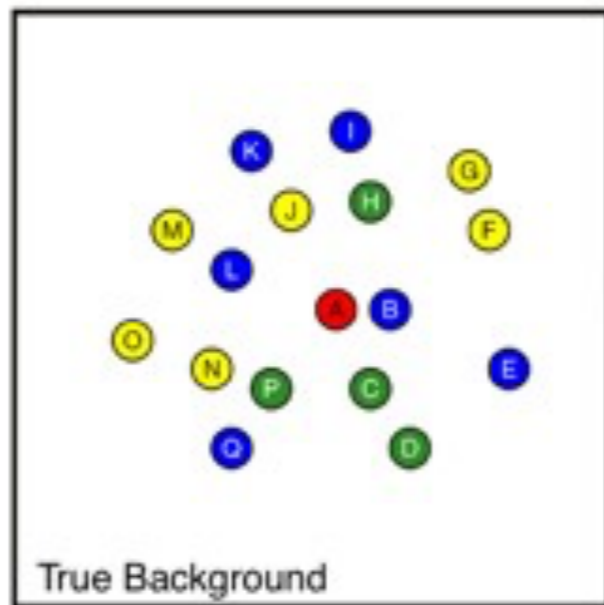
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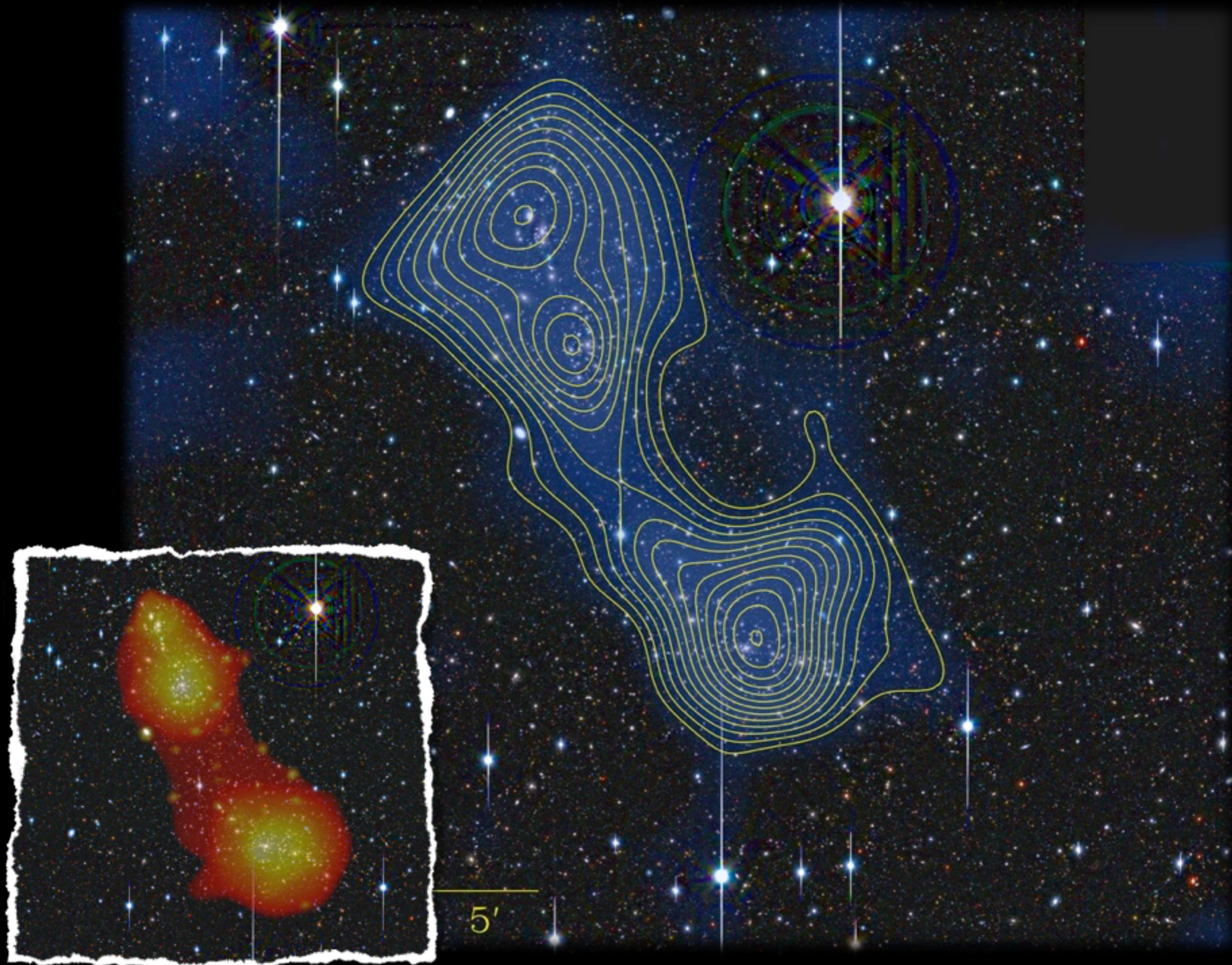


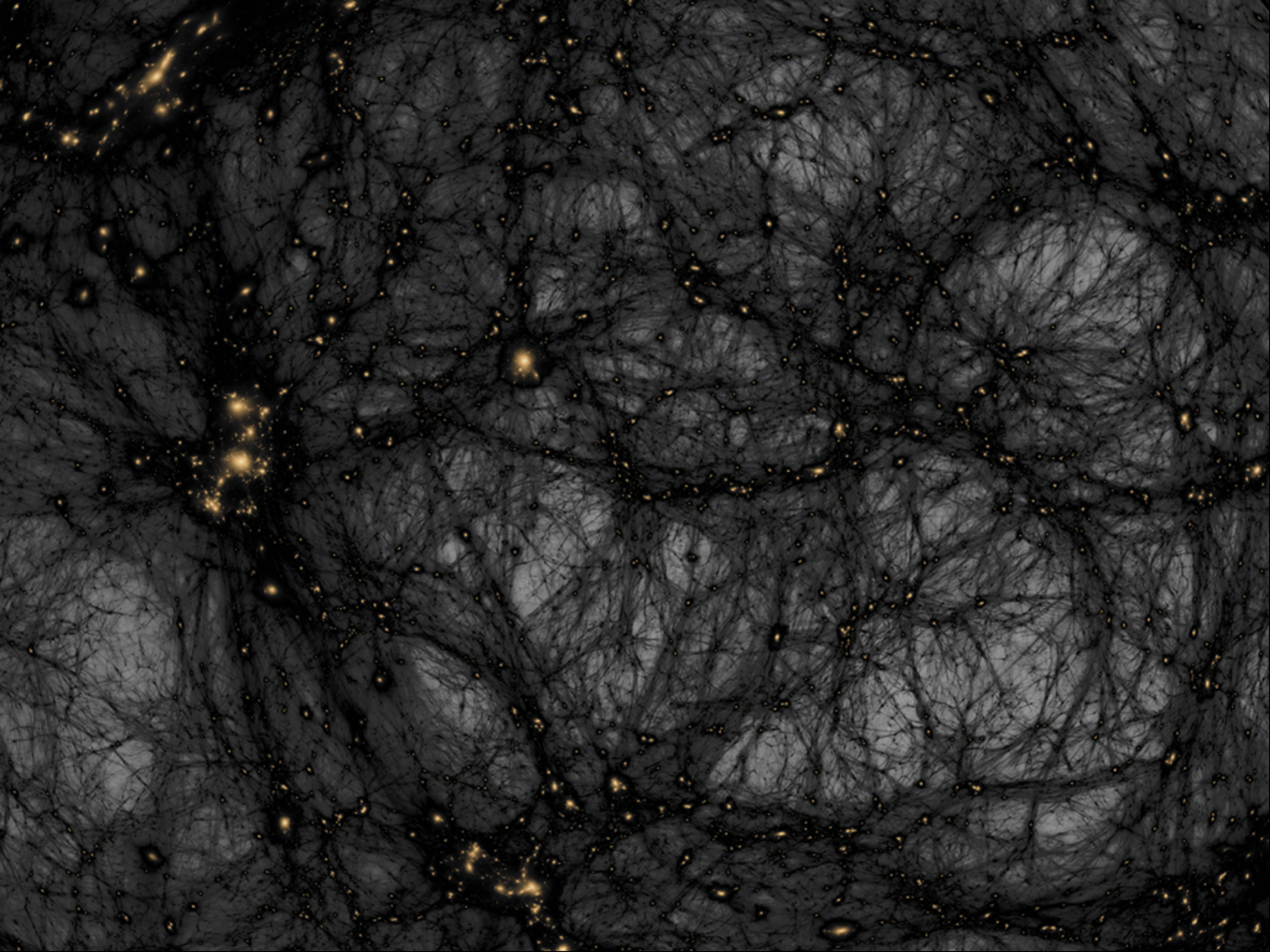
Chýbajúca normálna hmota

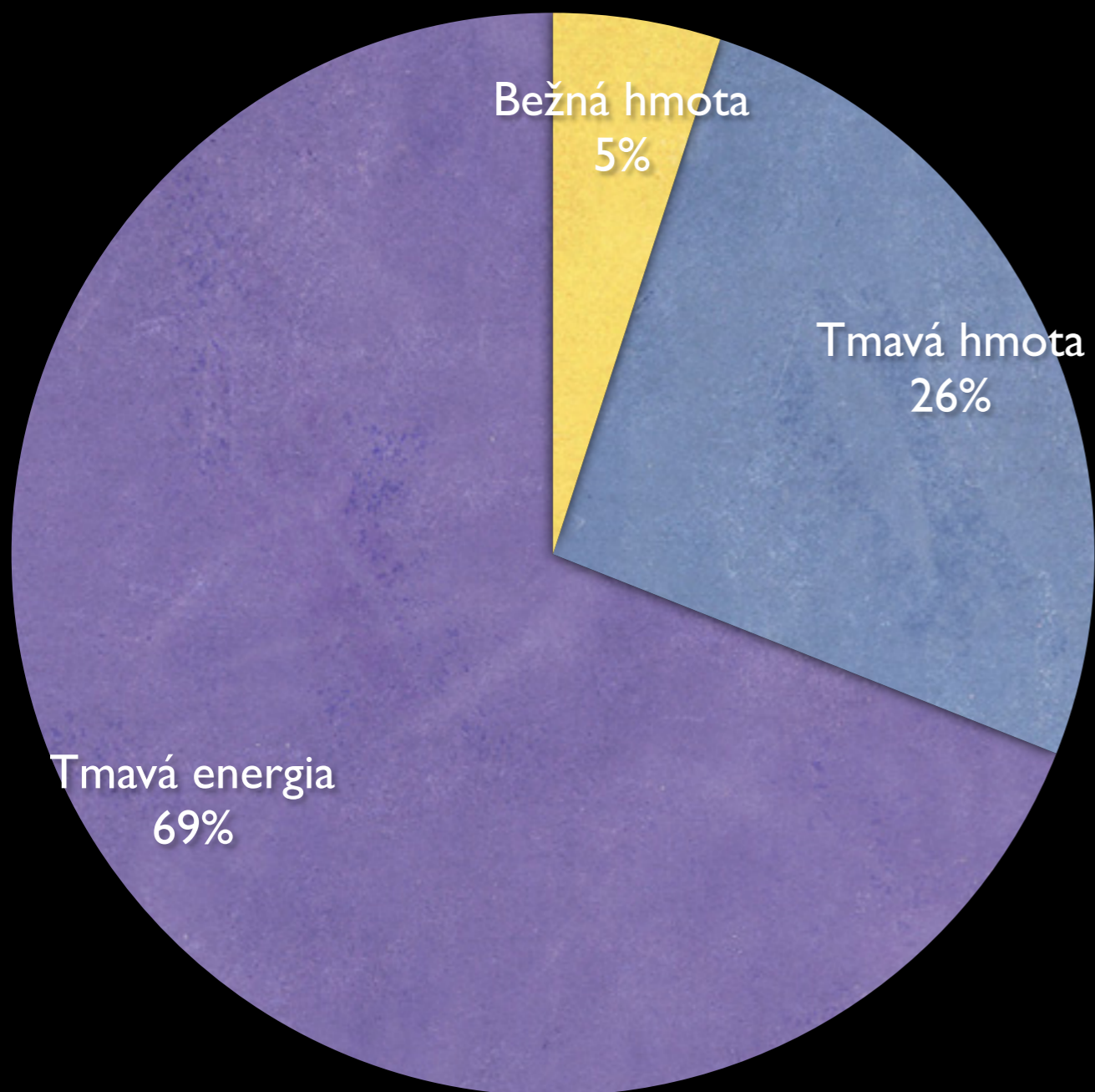


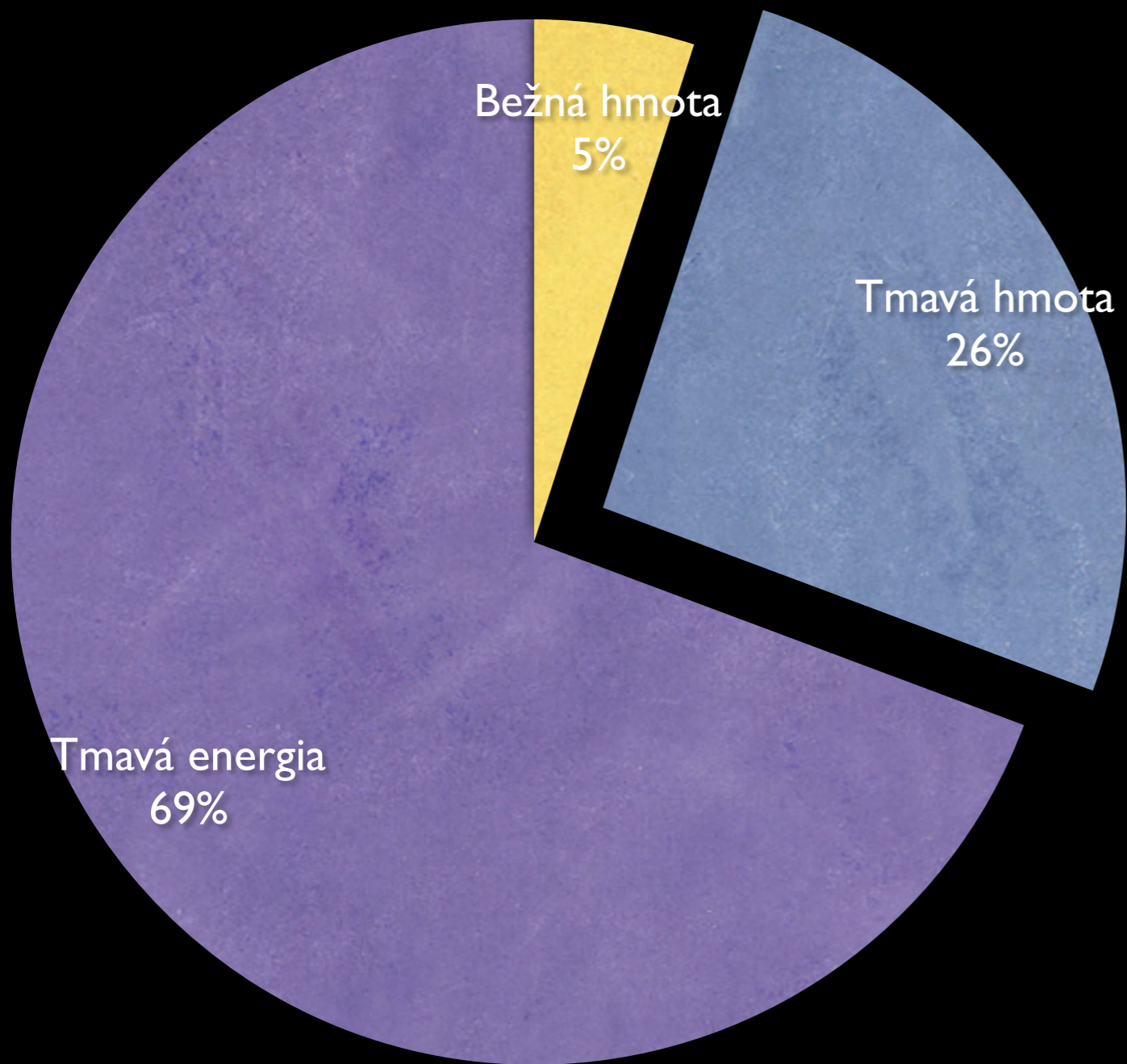


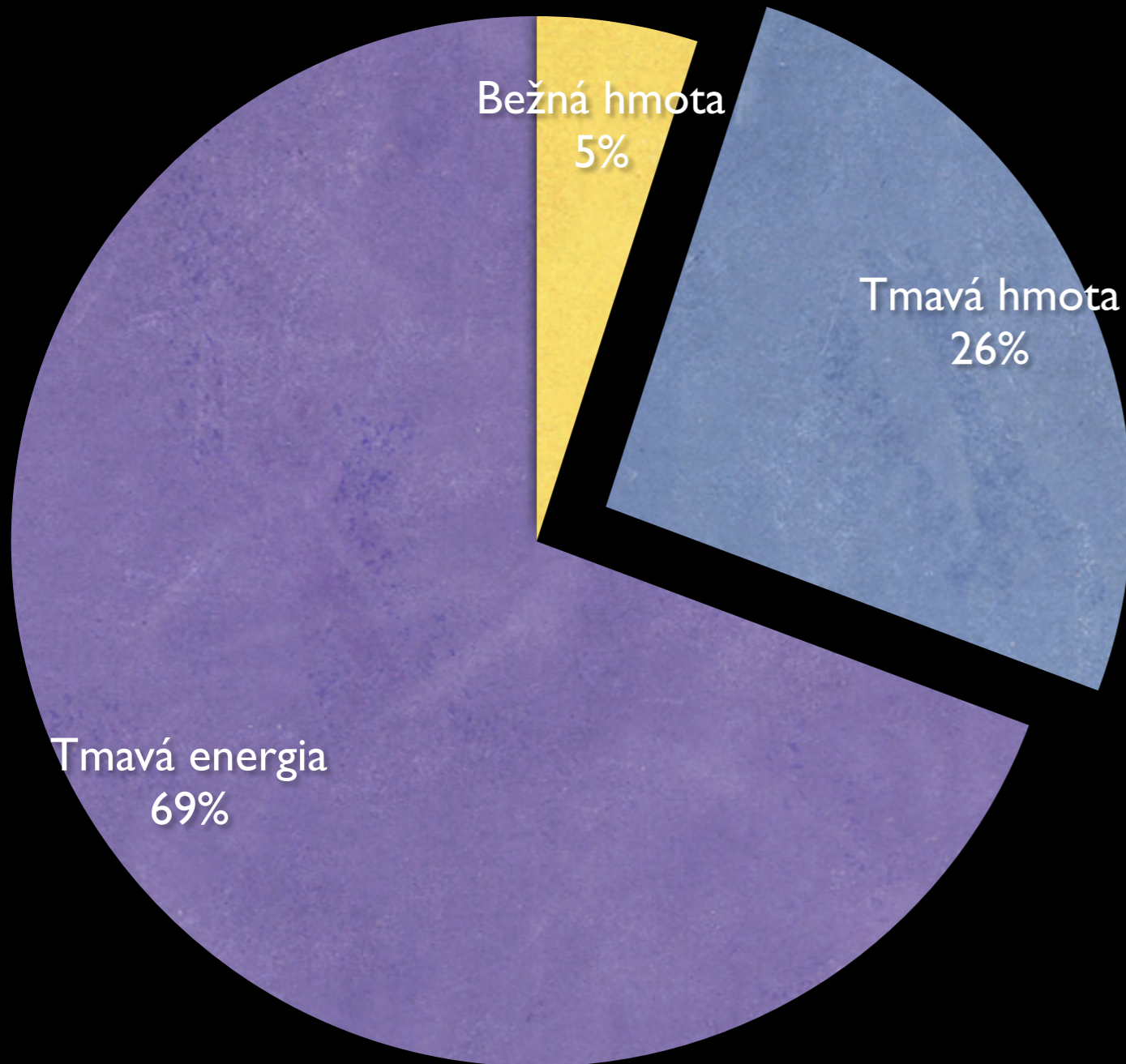
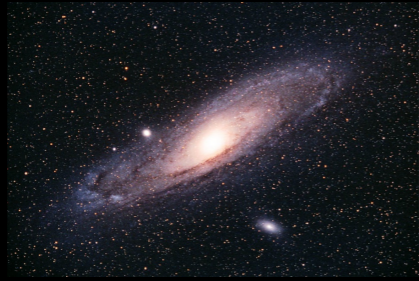


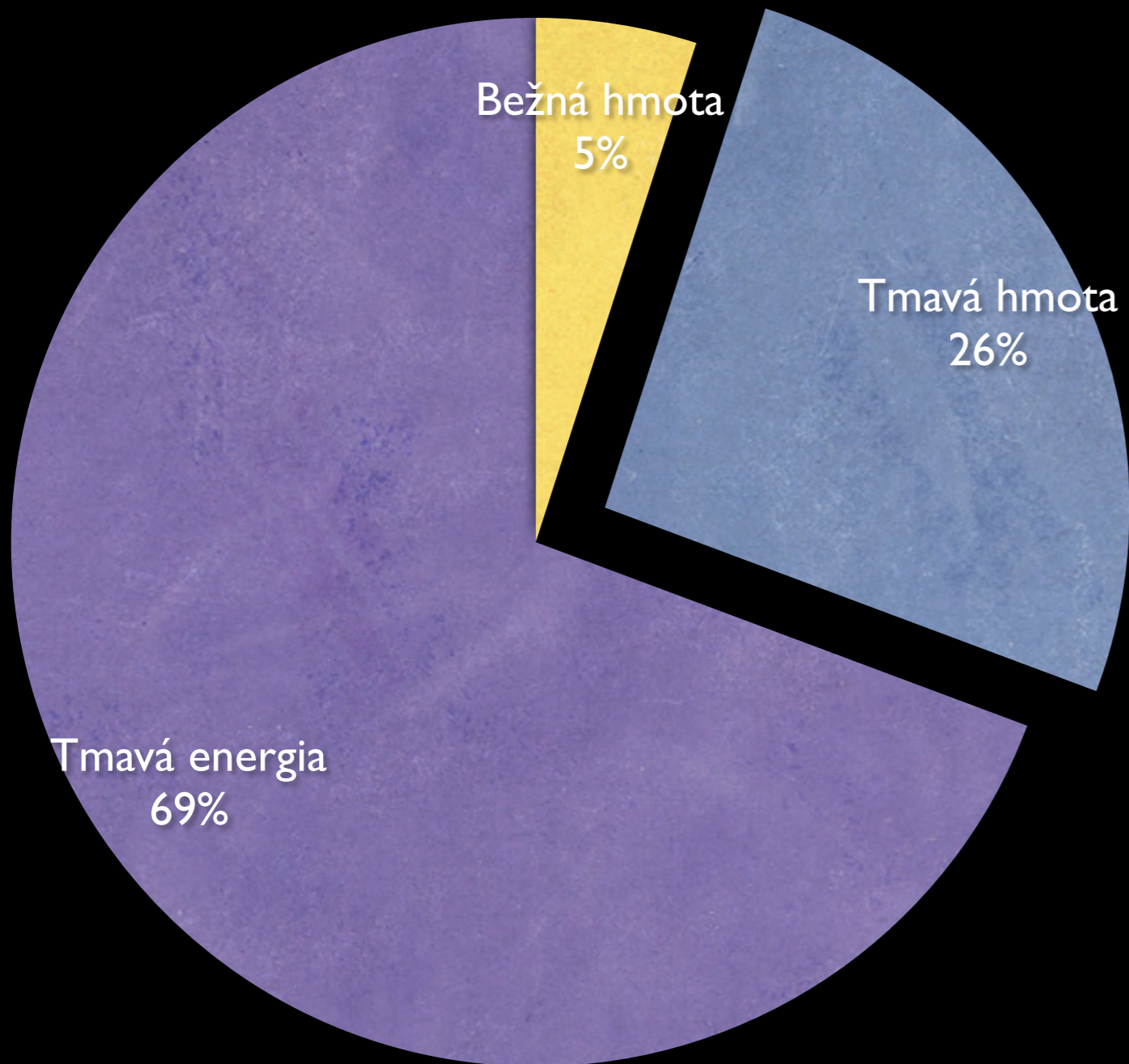
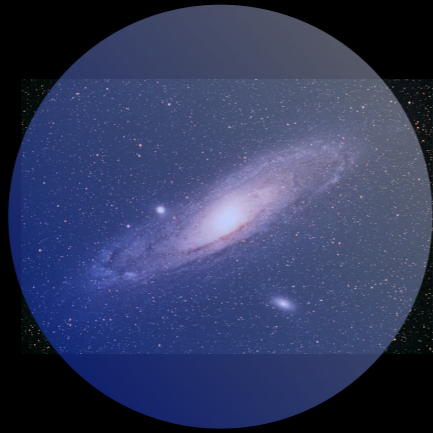


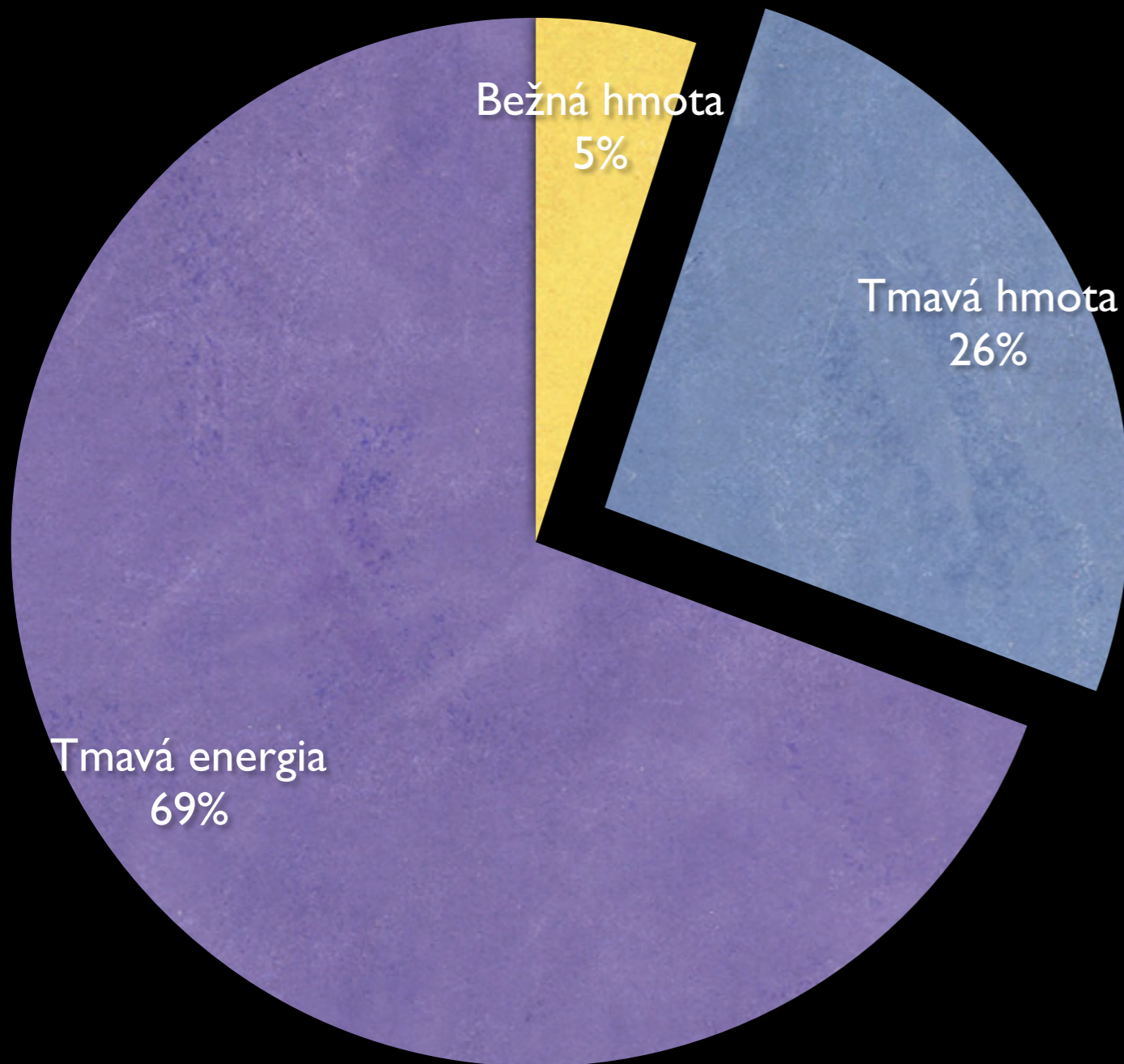
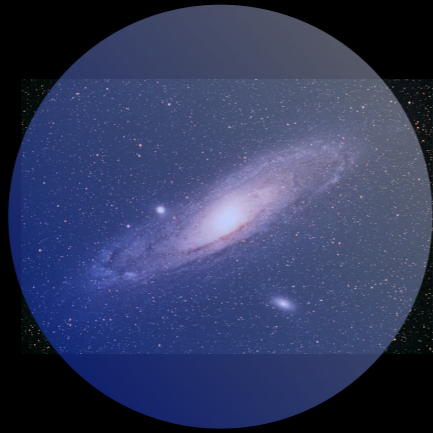


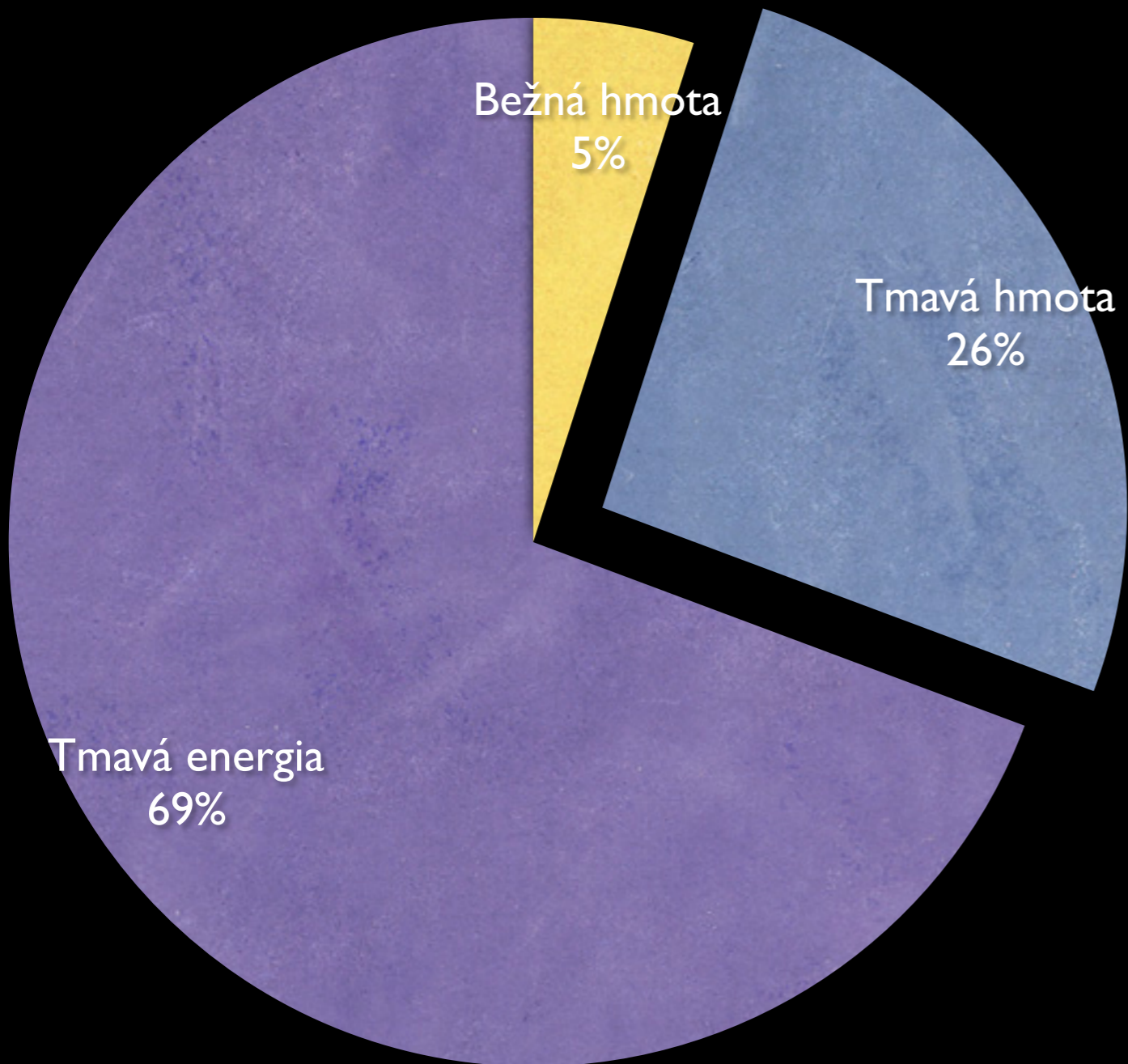
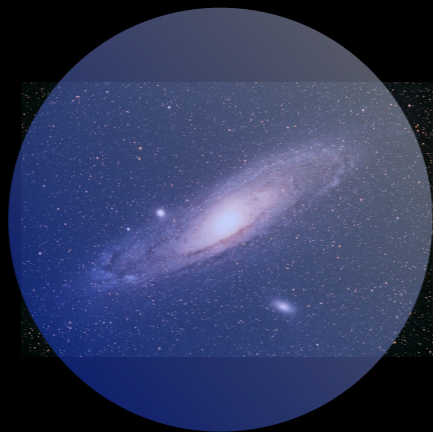


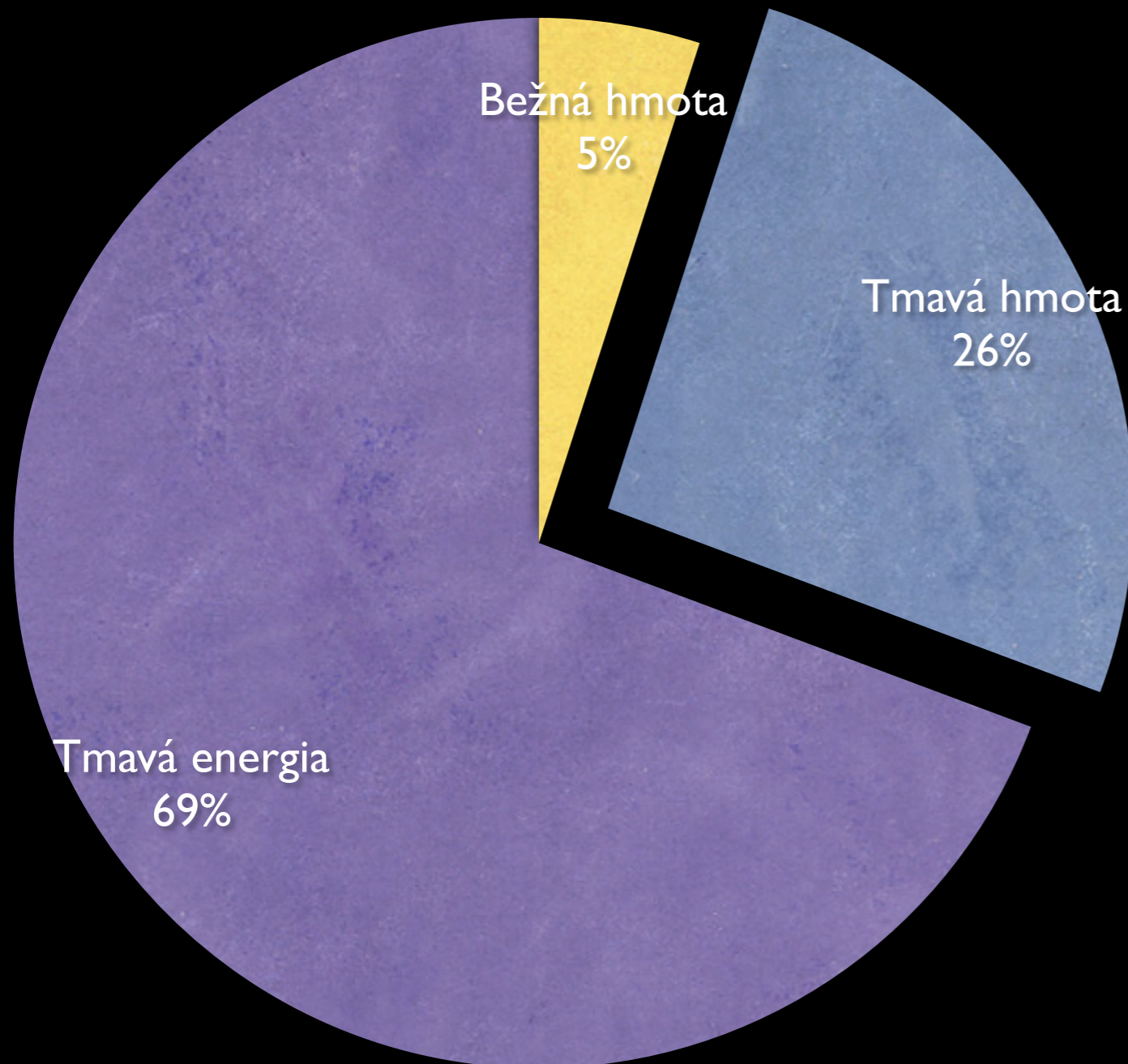
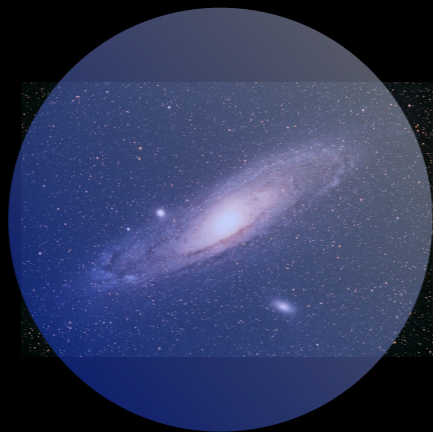


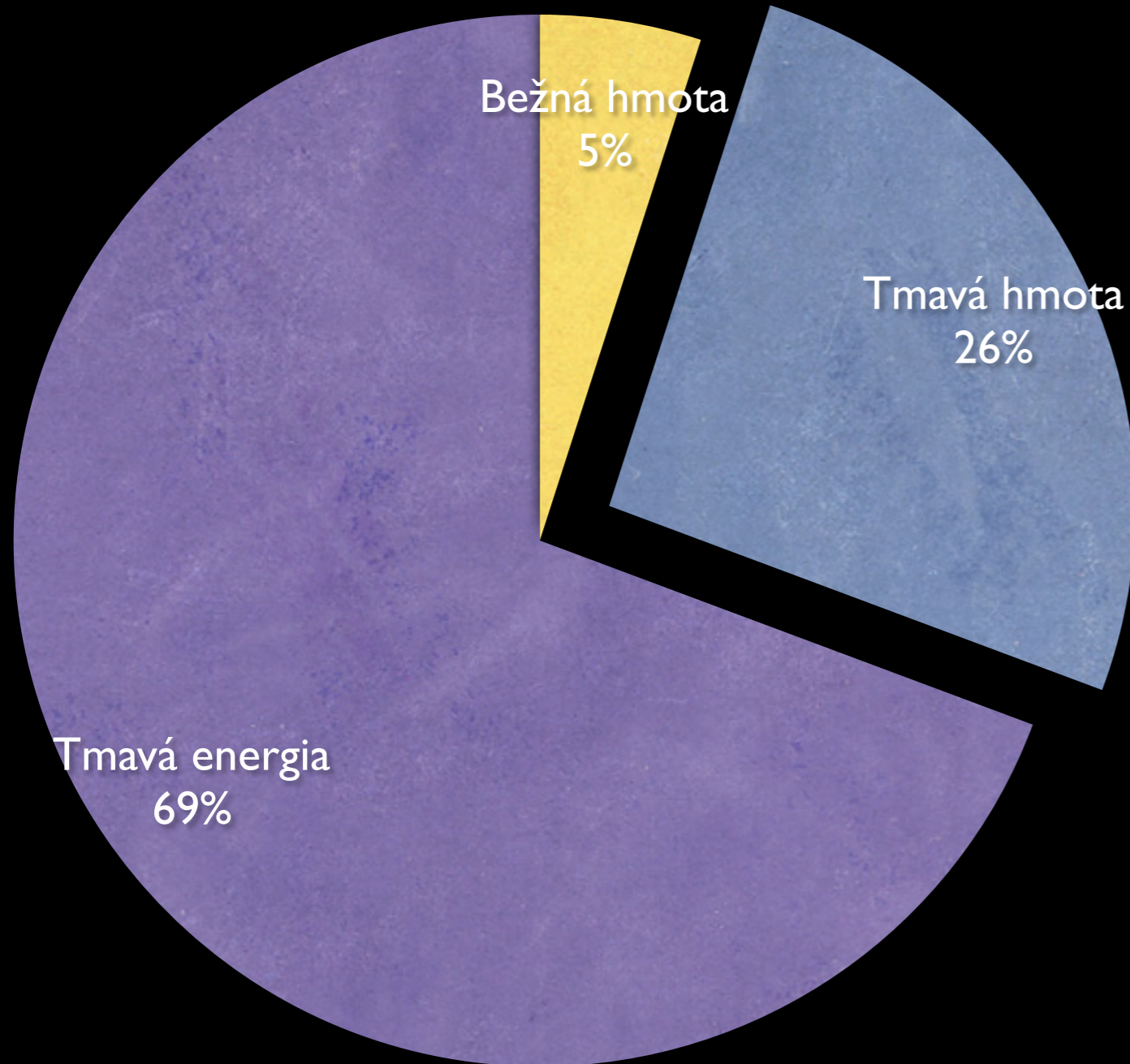
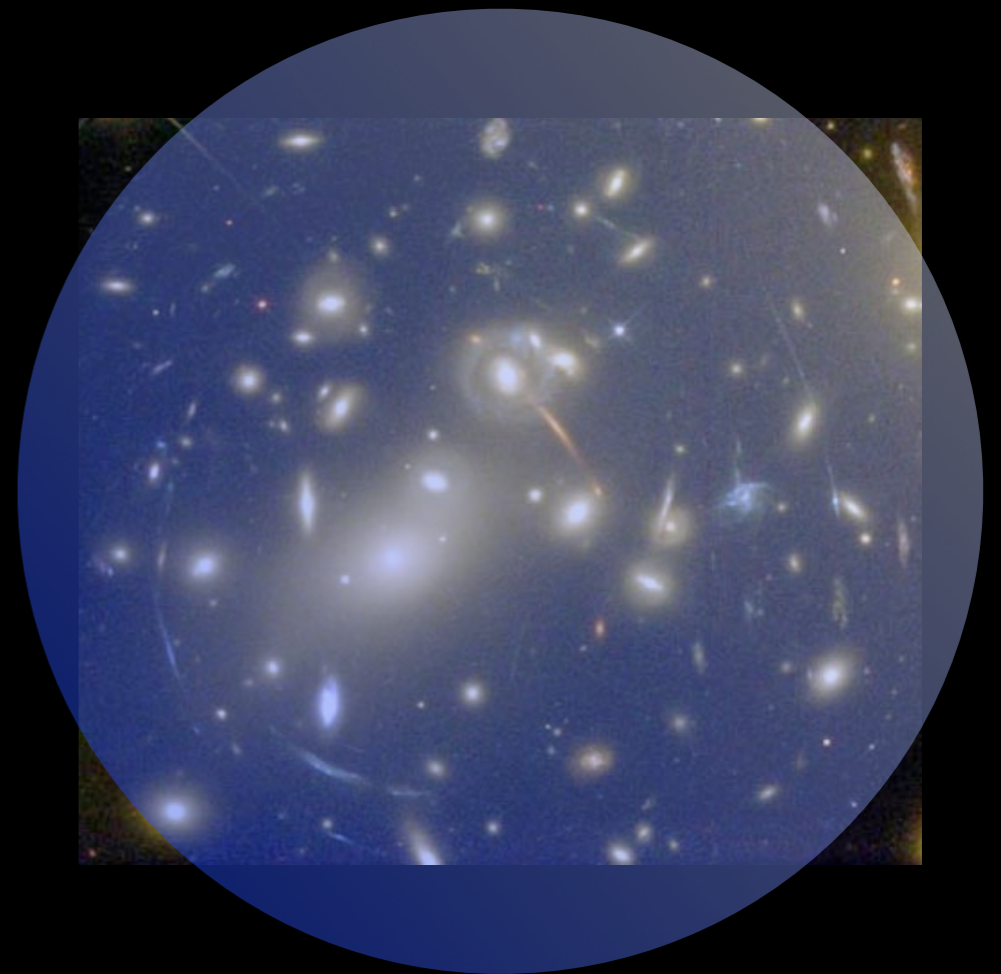
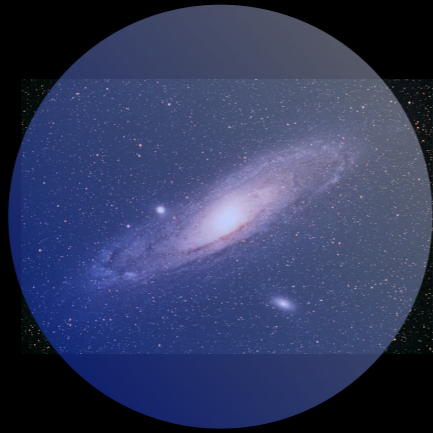










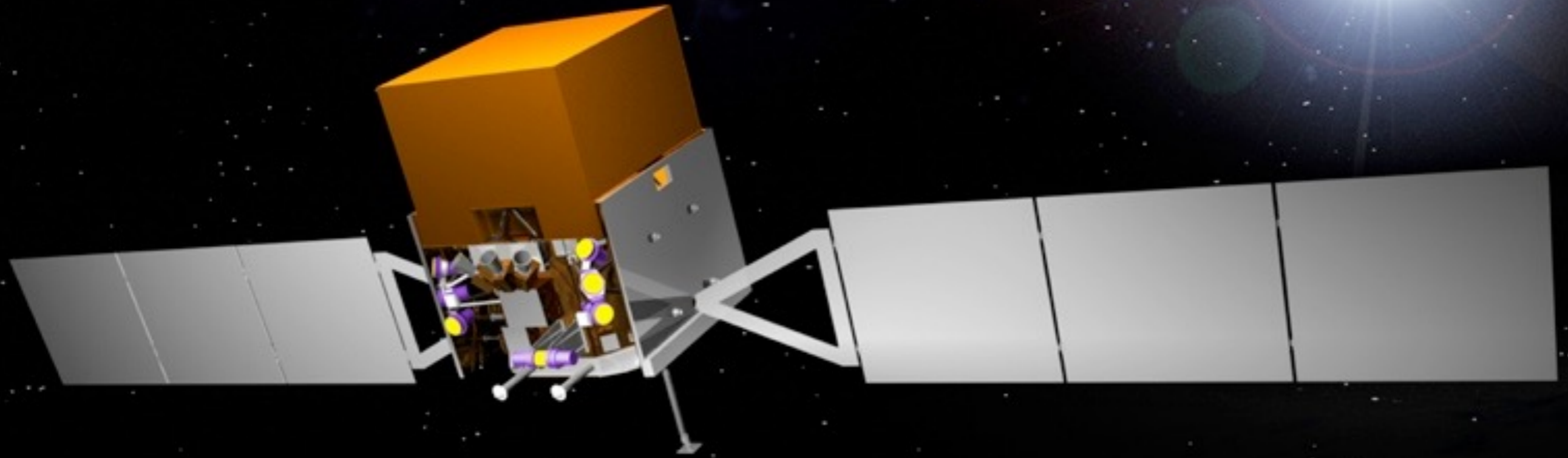


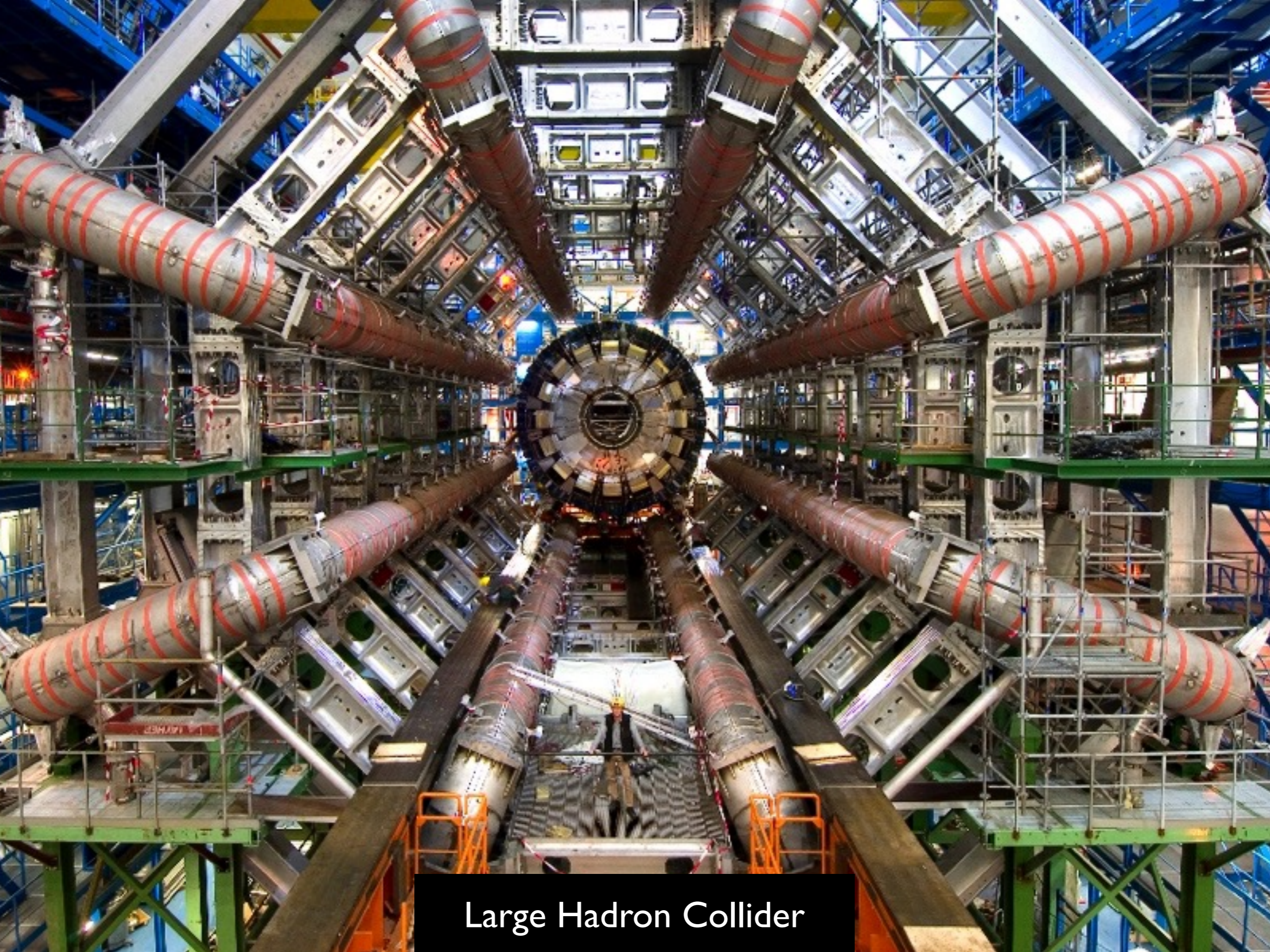


Cryogenic Dark Matter Search

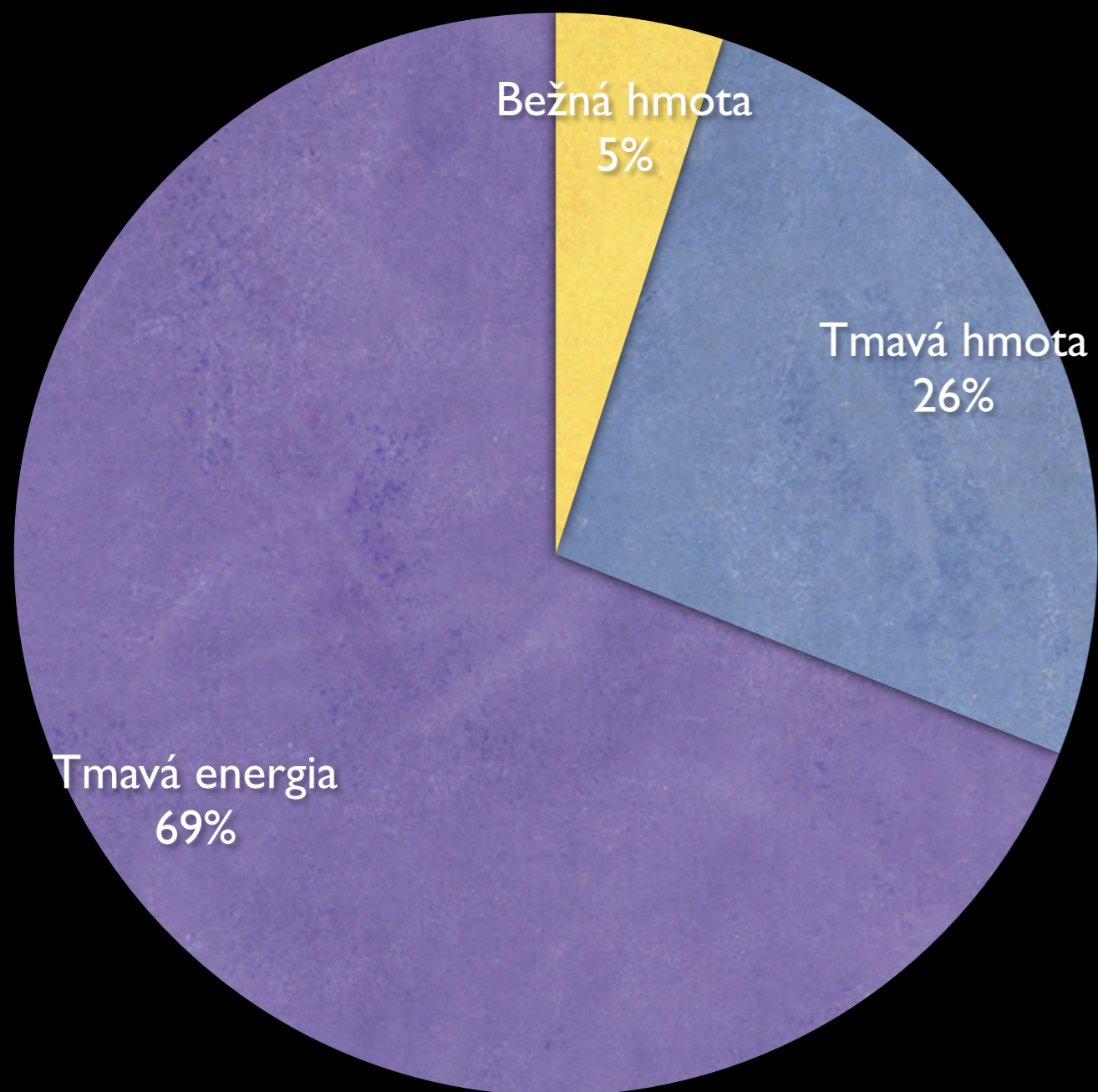


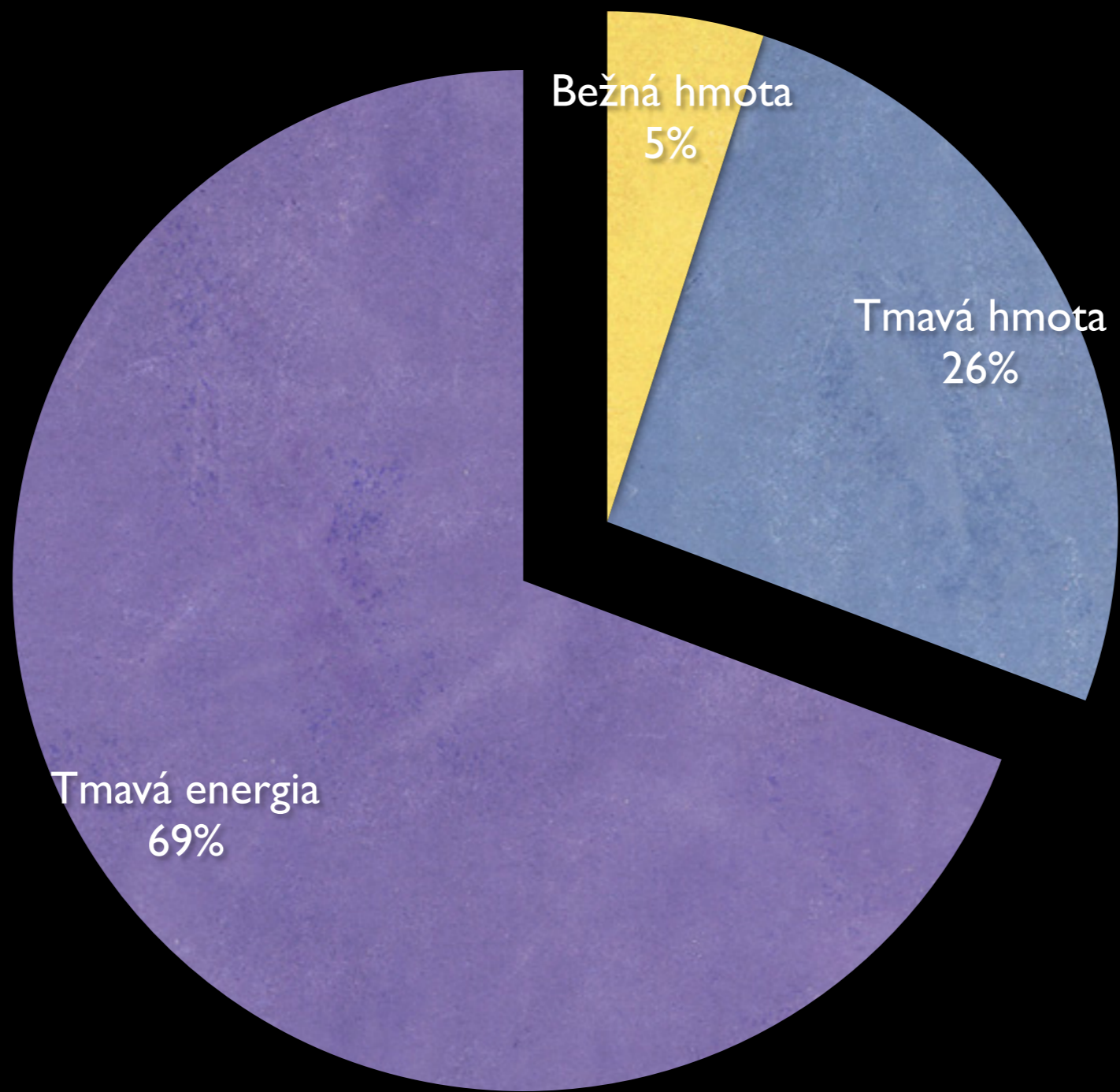
The Fermi Gamma-Ray Space Telescope





Large Hadron Collider





Objav rozpínania vesmíru

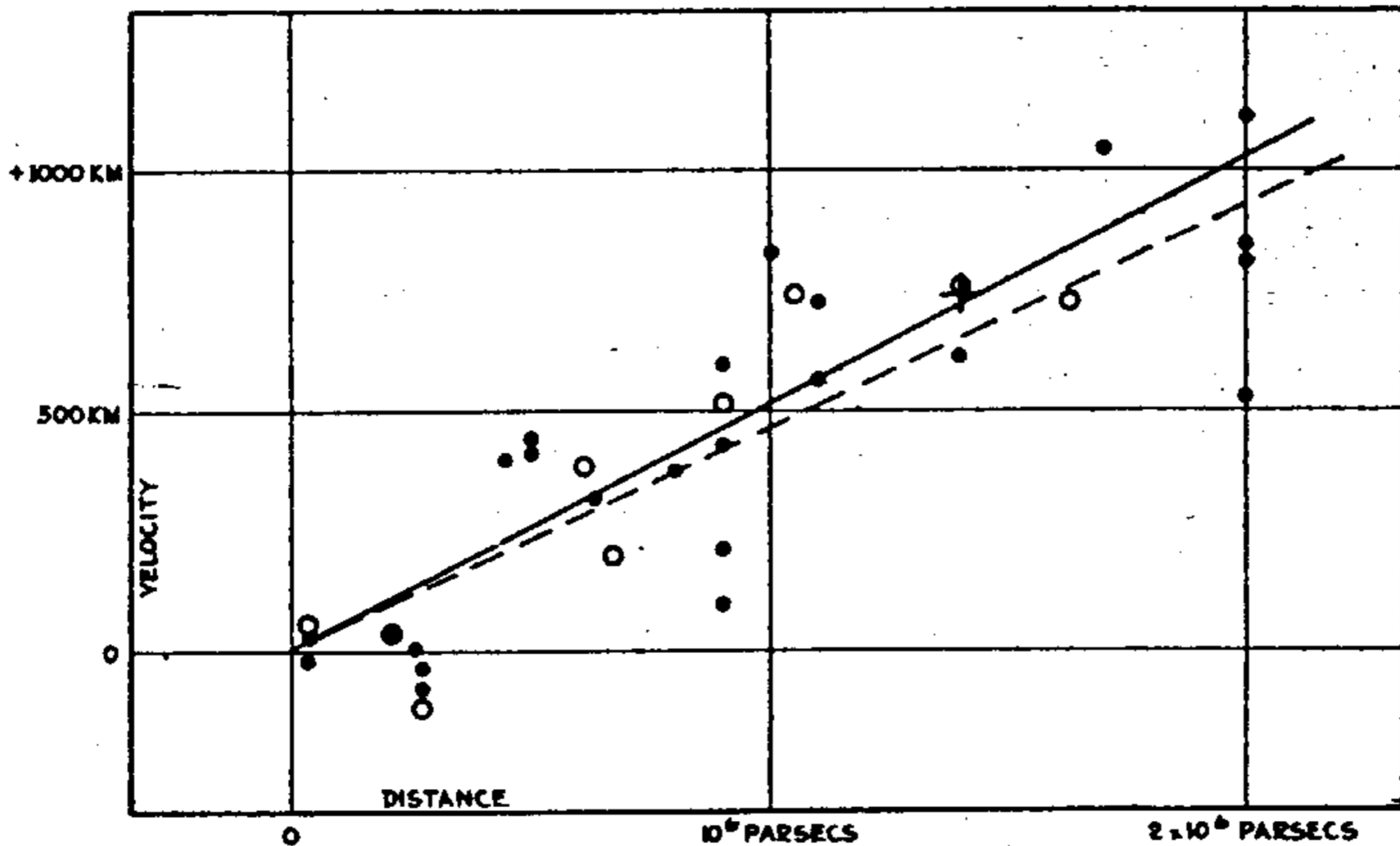


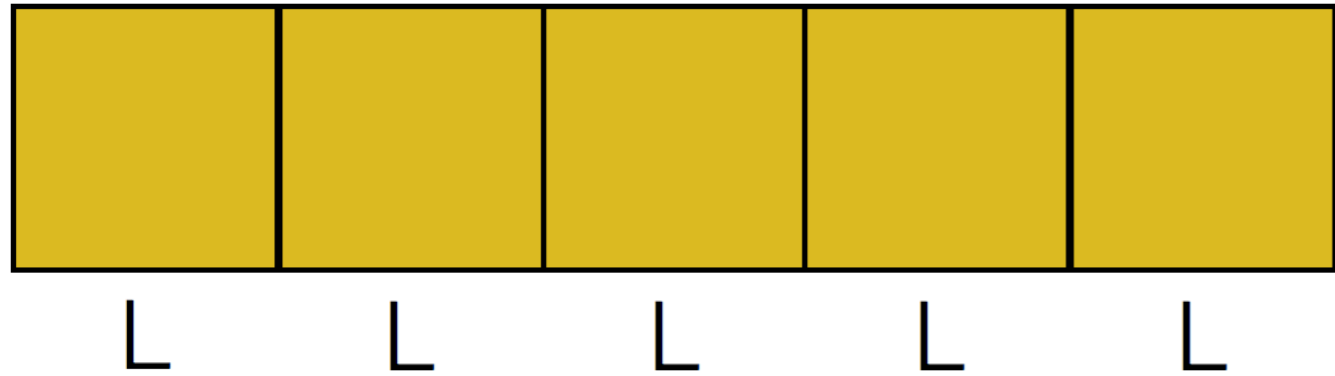
FIGURE 1

$$v = H \cdot d$$

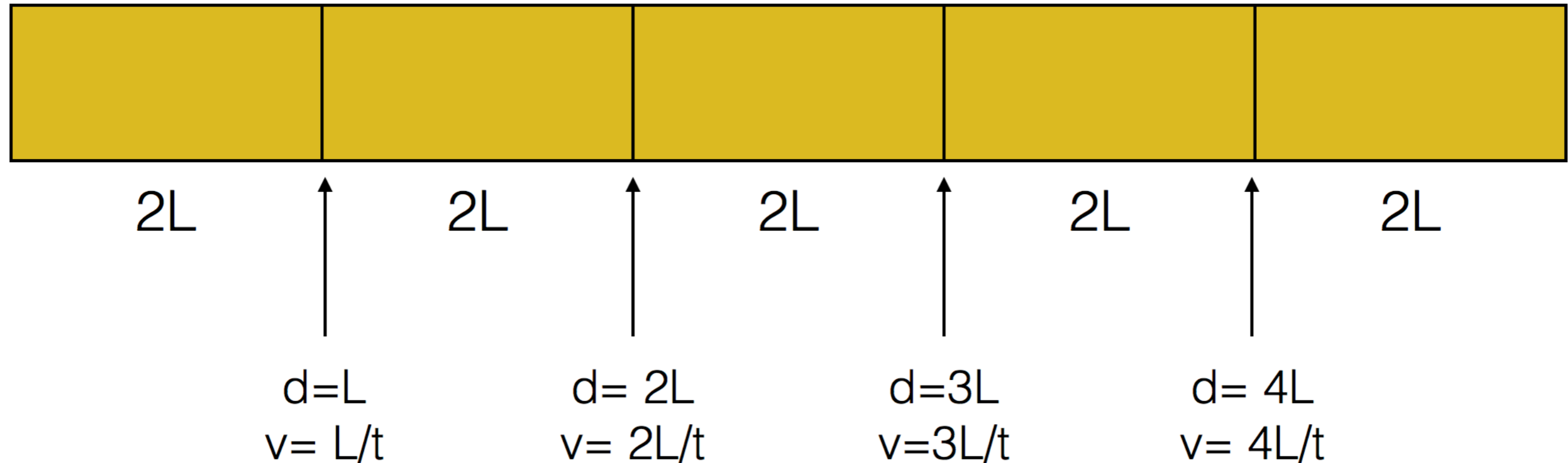
$H = 500 \text{ km/s/Mpc}$, Hubble 1929 (dnešná hodnota $\sim 70 \text{ km/s/Mpc}$)

What does cosmic expansion mean?

Imagine an elastic band:



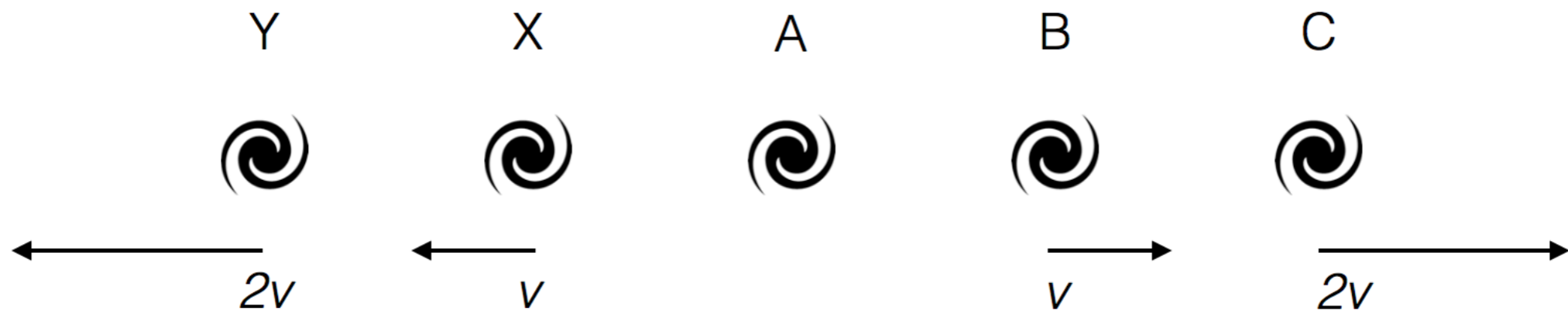
Now, someone stretched it out to double its initial size:



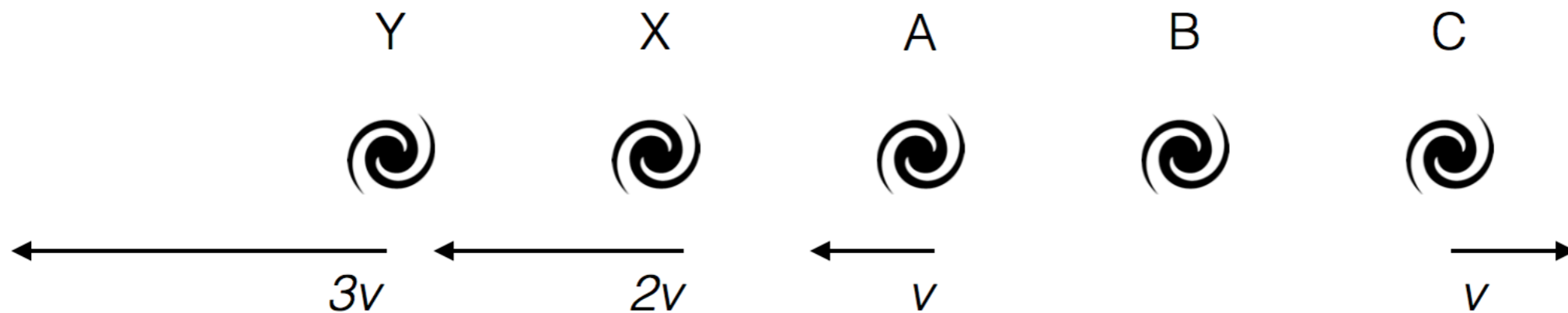
We recover $v \propto d$!

But the Universe is NOT expanding away from any “privileged” point that remains fixed in space!

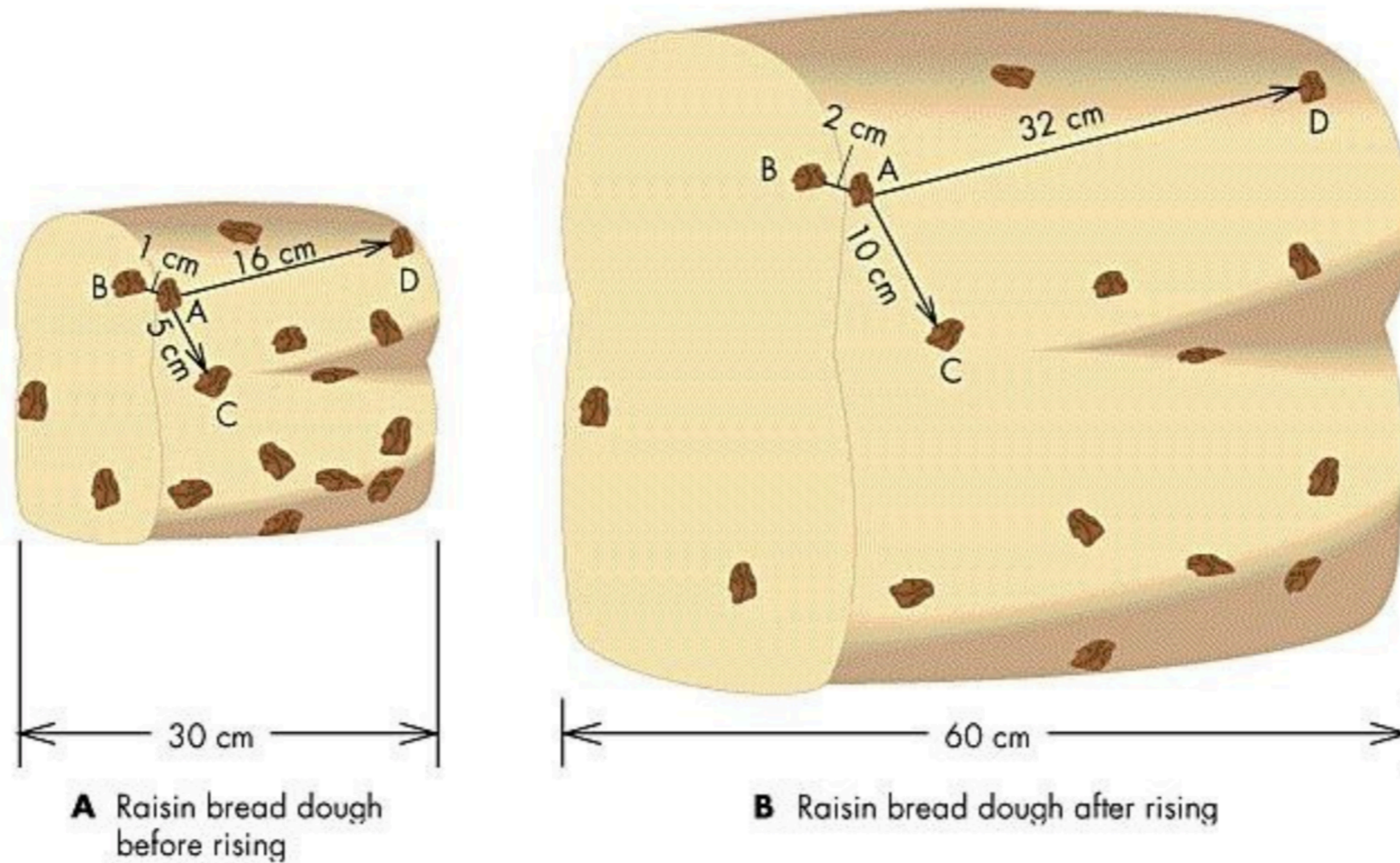
If you live in galaxy A



If you live in galaxy B



3D intuitive equivalent to cosmic expansion (‘expanding raisin bread model’)



But, in the Universe, there is no dough...
the space itself is growing





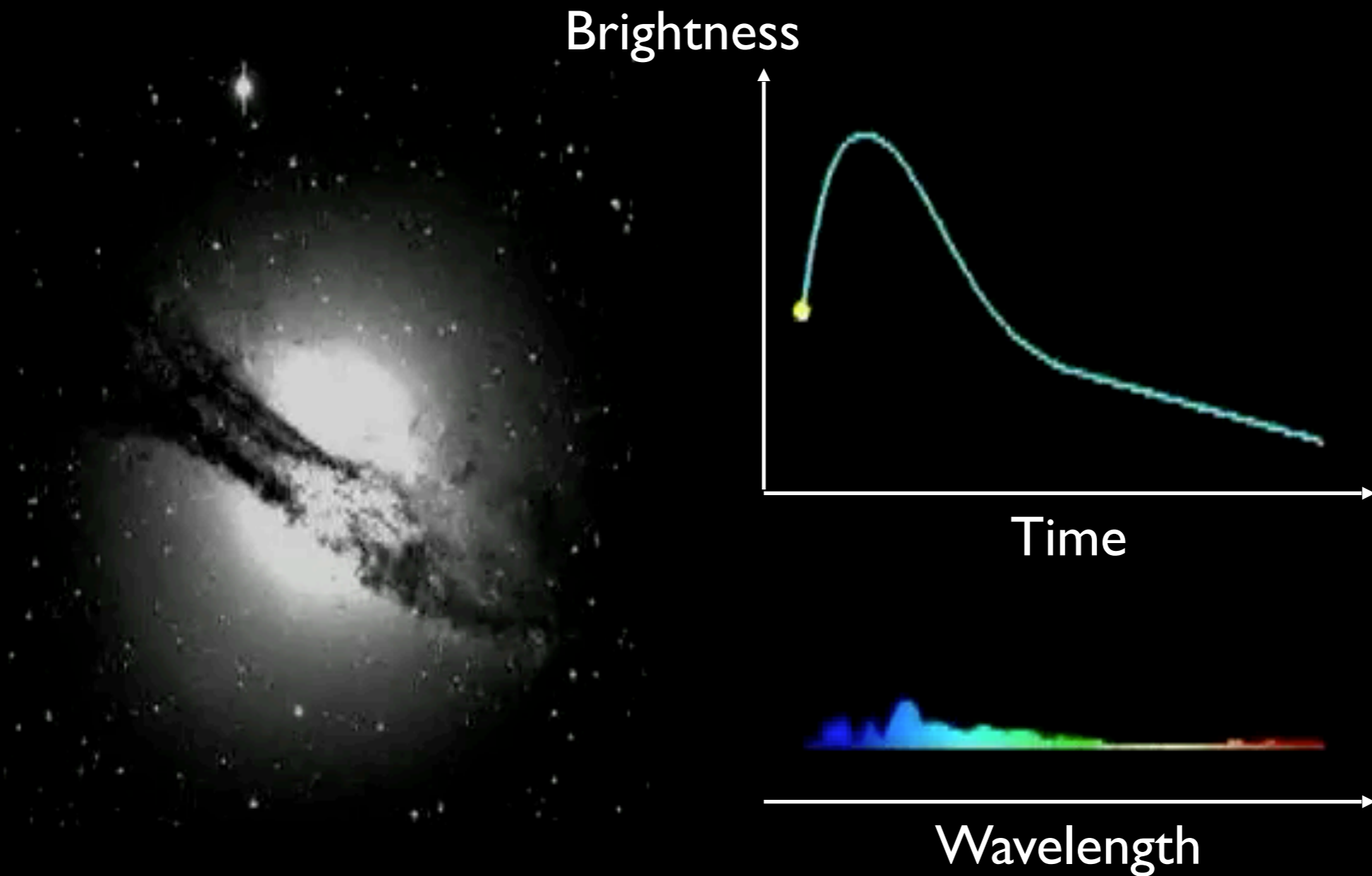




Štandardné sviečky vo Vesmíre: supernovy typu Ia

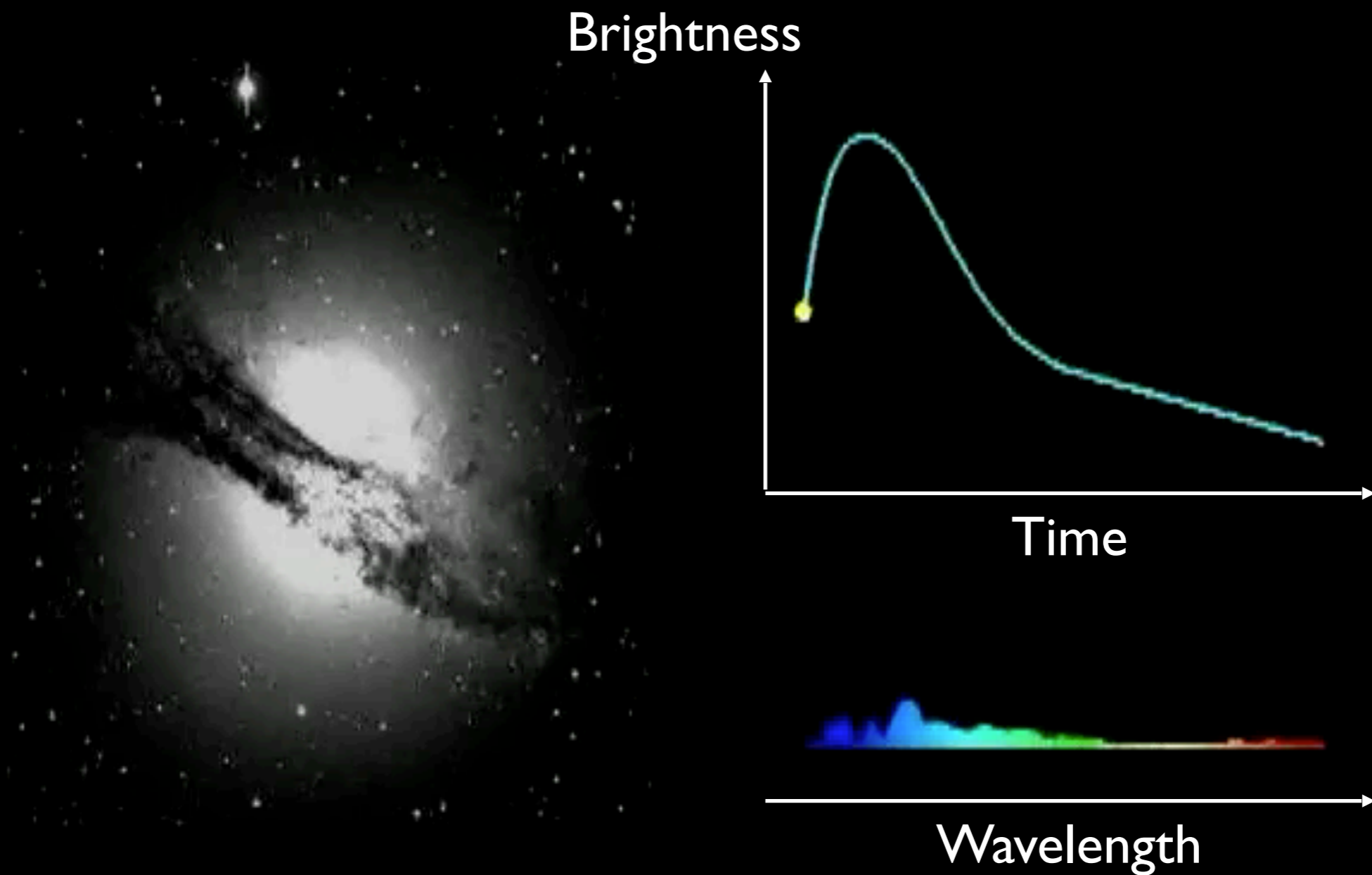


Štandardné sviečky vo Vesmíre: supernovy typu Ia



Supernova Cosmology Project (P. Nugent: spectral sequence; A. Conley: image sequence) with the help of Lawrence Berkeley National Laboratory's Computer Visualization Laboratory (N. Johnston: animation) at the National Energy Research Scientific Computing Center.

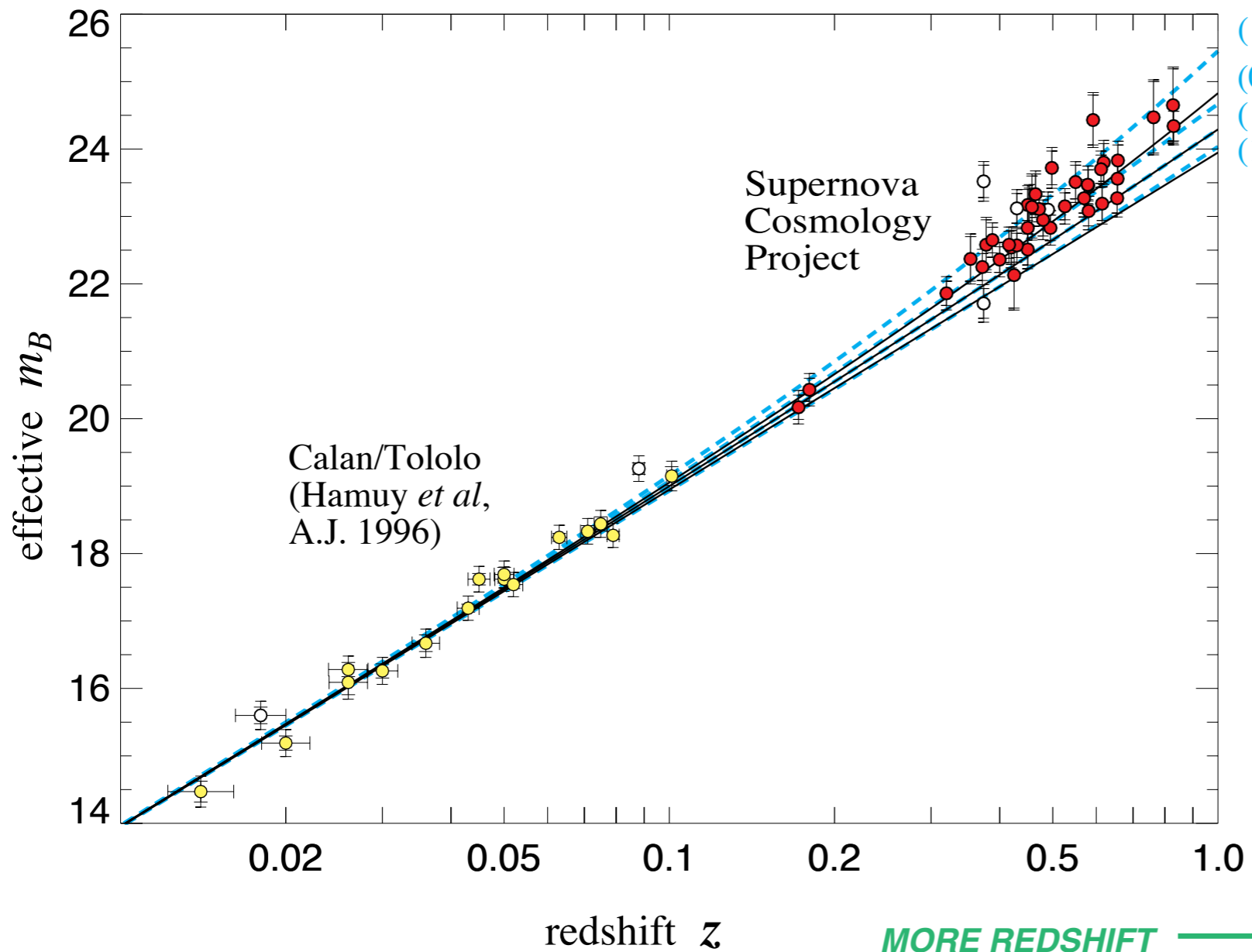
Štandardné sviečky vo Vesmíre: supernovy typu Ia



Supernova Cosmology Project (P. Nugent: spectral sequence; A. Conley: image sequence) with the help of Lawrence Berkeley National Laboratory's Computer Visualization Laboratory (N. Johnston: animation) at the National Energy Research Scientific Computing Center.

↑
FAINTER
 (Farther)
 (Further back in time)

Perlmutter, *et al.* (1998)



$(\Omega_M, \Omega_\Lambda) =$
 (0, 1)
 (0.5, 0.5) (0, 0)
 (1, 0) (1, 0)
 (1.5, -0.5) (2, 0)
 Flat $\Lambda = 0$

<http://www.lbl.gov/Science-Articles/Archive/Phys-Gruber-Prize-2007.html>

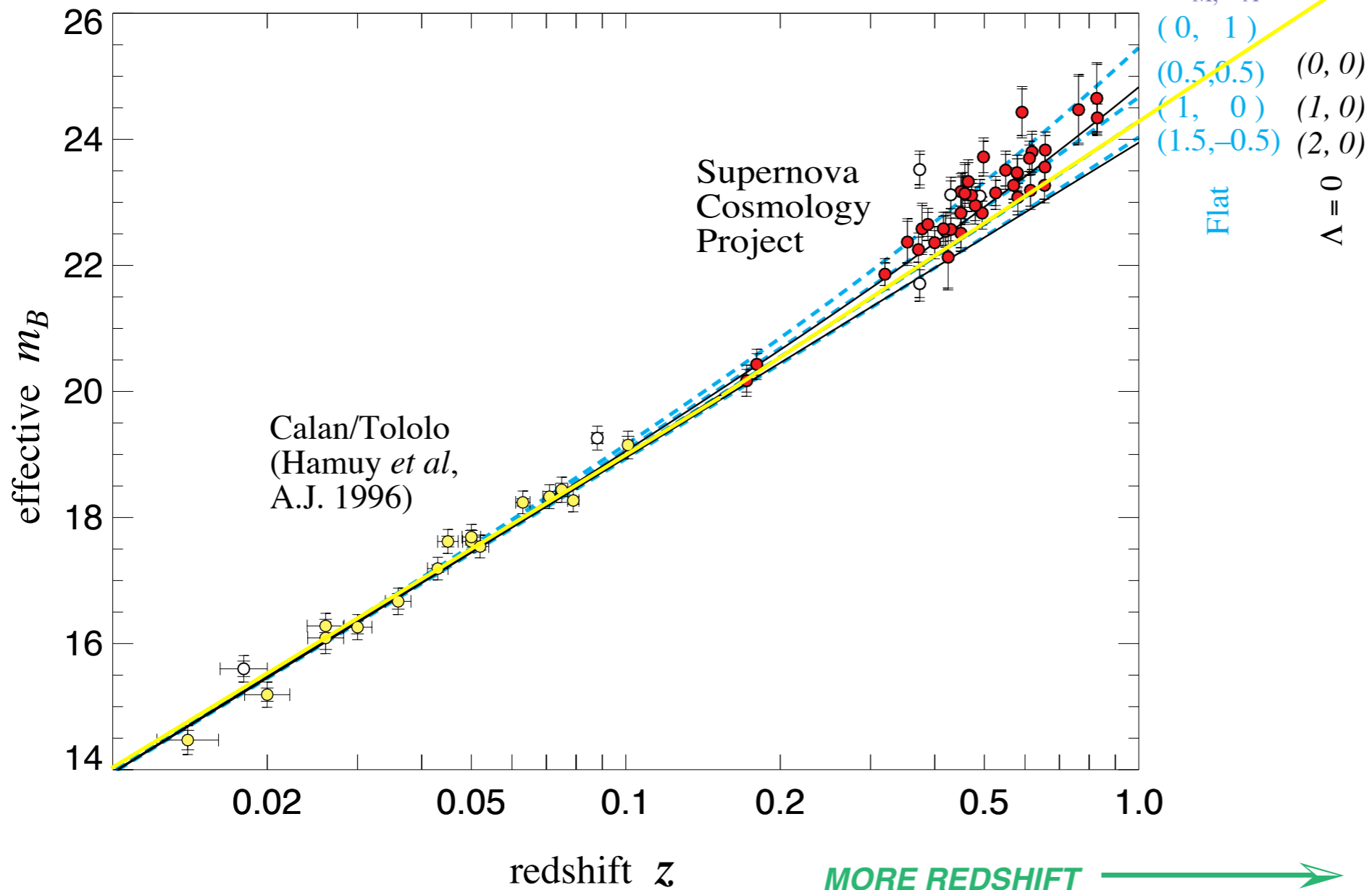
→
MORE REDSHIFT
 (More total expansion of universe
 since the supernova explosion)

Also Riess *et al.* (1998)

↑
FAINTER
 (Farther)
 (Further back in time)



Perlmutter, *et al.* (1998)



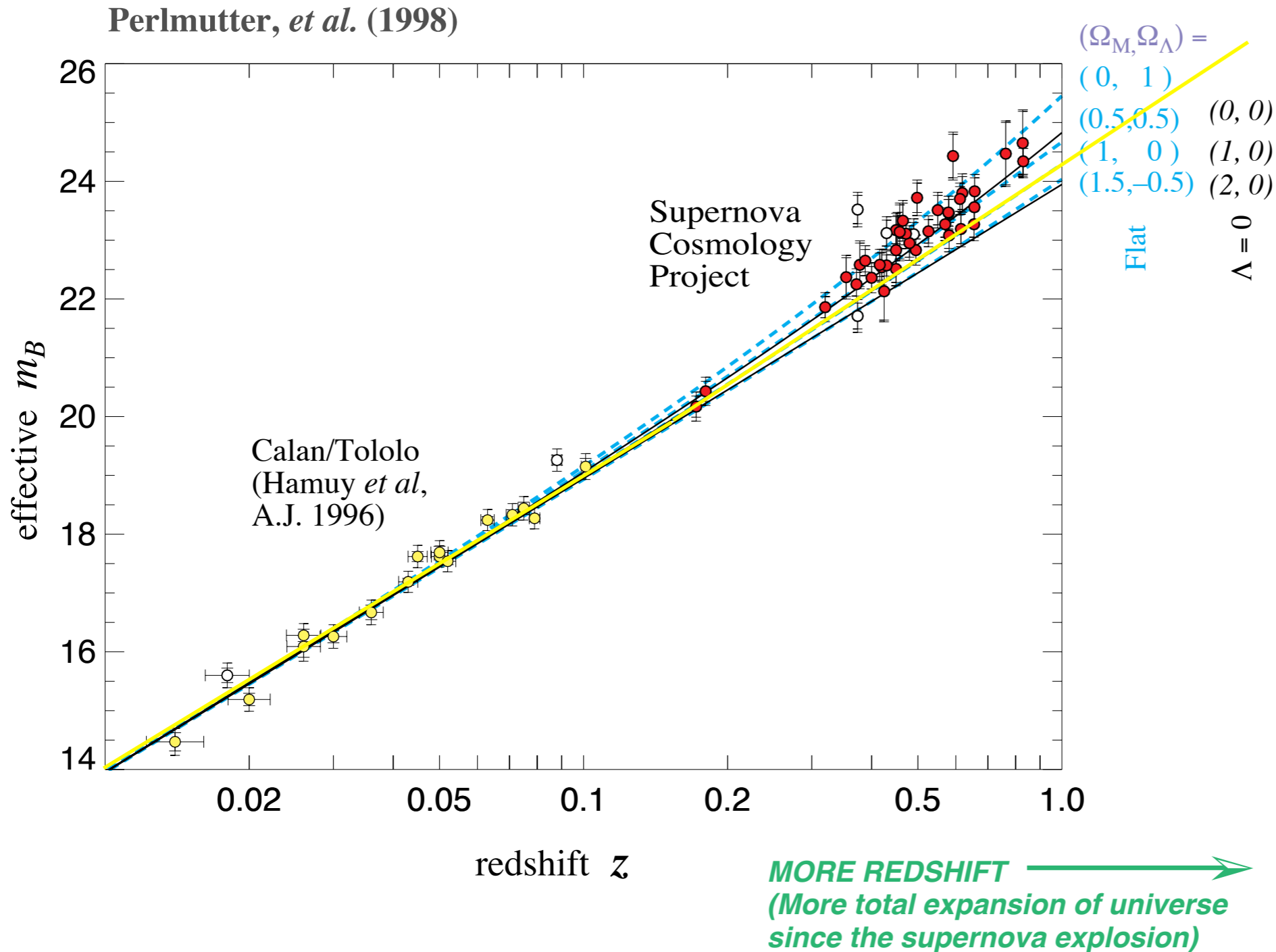
<http://www.lbl.gov/Science-Articles/Archive/Phys-Gruber-Prize-2007.html>

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- For a given brightness (distance), redshift is less than expected.

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(Further back in time)

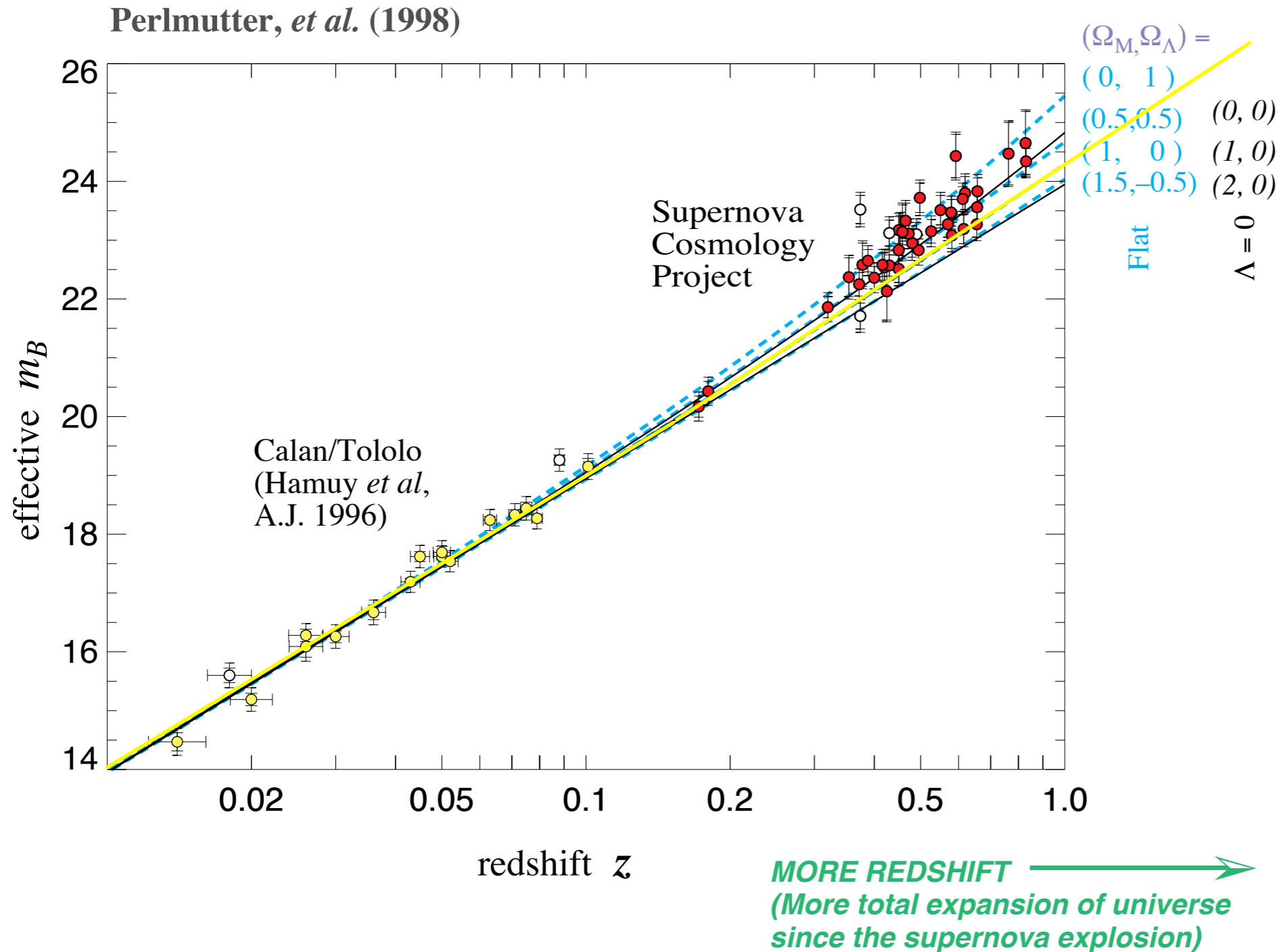


<http://www.lbl.gov/Science-Articles/Archive/Phys-Gruber-Prize-2007.html>

Also Riess *et al.* (1998)

- For a given brightness (distance), redshift is less than expected.
- Universe was expanding at less than the “expected” rate in the past.

↑
FAINTER
(Farther)
(Further back in time)

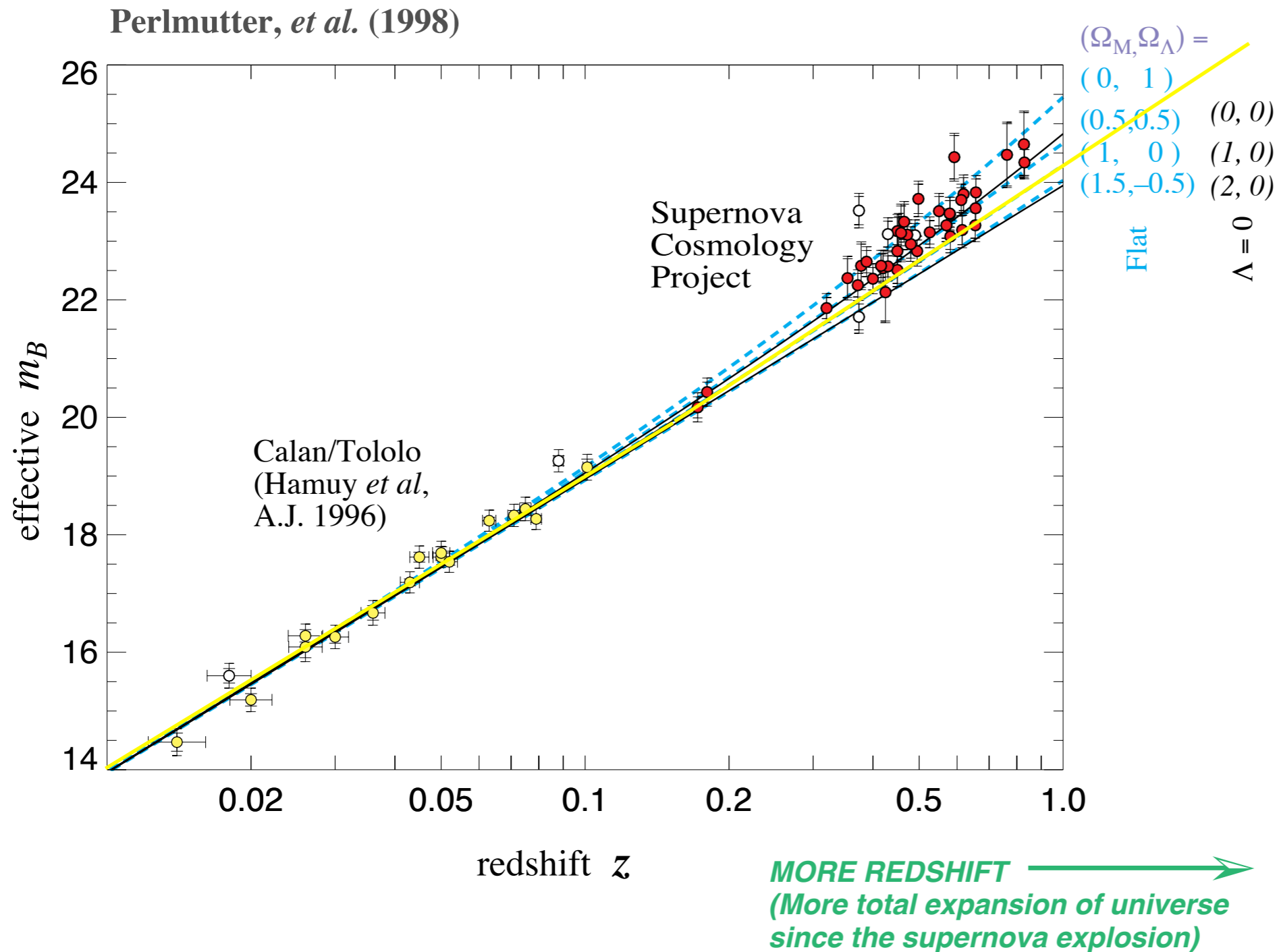


<http://www.lbl.gov/Science-Articles/Archive/Phys-Gruber-Prize-2007.html>

Also Riess *et al.* (1998)

- For a given brightness (distance), redshift is less than expected.
- Universe was expanding at less than the “expected” rate in the past.
- Universe is actually expanding at an ever-increasing rate today!

↑
FAINTER
(Farther)
(Further back in time)



<http://www.lbl.gov/Science-Articles/Archive/Phys-Gruber-Prize-2007.html>

Also Riess *et al.* (1998)

